International Lunar Network Communications Working Group

Final Report

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1.0 EXECUTIVE SUMMARY

The National Research Council (NRC) of the National Academies affirmed the following in its report *The Scientific Context for Exploration of the Moon* (2007) (SCEM)[1]:

> "It is the unanimous consensus of the (NRC) committee that the Moon offers profound scientific value...A vigorous near term robotic exploration program providing global access is central to the next phase of scientific exploration of the Moon and is necessary both to prepare for the efficient utilization of human presence and to maintain scientific momentum …"

In that report, the NRC strongly recommended establishing a network of four to eight seismic monitoring nodes on the lunar surface. Recognizing the formidable scope of this scientific challenge, NASA reached out to sister agencies around the world and in March 2008 proposed a partnership, the International Lunar Network (ILN), to meet this scientific challenge. The ILN was conceived as a multi-space agency partnership to pursue scientific exploration of the Moon with the goal of maximizing the scientific return to all of the participants in the ILN concept. Initial formation of the ILN partnership was accomplished with the signing of a non-binding Statement Of Intent (SOI) in July 2008 by nine space agencies: Agenzia Spaziale Italiana (ASI), British National Space Centre (BNSC), Centre National d'Etudes Spatiales (CNES), Canadian Space Agency (CSA), Deutsches Zentrum für Luft- und Raumfahrt (DLR), Indian Space Research Organization (ISRO), Japanese Aerospace Exploration Agency (JAXA), Korea Aerospace Research Institute (KARI), and the National Aeronautics and Space Administration (NASA). This partnership to coordinate exploration activities is consistent with the 31 May 2007 report *Global Exploration Strategy: The Framework for Coordination*[2], which articulated a shared vision of space exploration focused on solar system destinations where humans may someday live and work. Working together, several agencies may be able to accomplish what no single one of them can do by itself.

The major objective of the ILN partnership is to establish a robotic set of geophysical monitoring stations on the surface of the Moon for the purpose of providing significant scientific value to the exploration of the Moon for all involved partners. Participation in the ILN will come through the contribution of landers, orbiters, instrumentation, or other significant infrastructure contributions, including communications capabilities which in total will comprise the ILN. This network will be accomplished by the placing on the surface of the Moon, including its far side and/or polar regions, robotic landers or other vehicles equipped with instruments from an agreed-upon set of scientifically equivalent core instrumentation. The core set of instrumentation is fundamental to the ILN concept as it will allow inter-comparison of measurements obtained from the instruments of all ILN participants. As a principal of the ILN concept articulated in the SOI, participants agree to accept a defined set of core instruments and measurements, and to a policy of free and open exchange of data from those core instruments, although the data obtained may be proprietary among the participants for a certain period.

Each ILN node will include some number of "core" capabilities (e.g., seismic, heat flow, laser retro-reflectors (LRR)) that will be extant on each station, reflecting prioritized lunar science goals articulated in the SCEM. Individual ILN nodes may carry additional, unique experiments to study local or global lunar science. Such additional experiments might include atmospheric and dust instruments, plasma physics investigations, astronomical instruments, electromagnetic profiling of lunar regolith and crust, local geochemistry, and in situ resource utilization demonstrations.

On 24 July 2008, a letter of intent was signed by the ILN participants. At that time the Core Instrument and Communications Working Groups were formed and given the direction that they would focus on fully understanding the opportunities and advantages of the potential cooperation. In addition, the ILN Communications Working Group (ILN Comm WG) was provided with the following objectives and the outcomes are shown in Table 1.1.

Table 1.1.—ILN Communication WG Objectives and Outcomes

ILN Communication WG Objectives	Outcome
1. Support the ILN member discussions concerning member agencies' contributions in terms of communications capabilities and their operational period;	✓ Communication capabilities and potential contributions are understood. ✓ Agencies are ready to proceed to detailed analysis of options and preliminary negotiation of contributions.
2. Accept science and instrument requirements from the ILN Core Instrument WG;	- ILN Core Instrument WG was unable to provide input in time for this report.
3. Determine ILN communications requirements derived from individual member inputs and the Core Instrument WG's requirements;	✓ NASA's Science Definition Team (SDT), ASI's MAGIA and Sardinia Radio Telescope (SRT), BNSC's Moon Lightweight Interior and Telecoms Experiment (MoonLITE), CNES's Lunar Geophysical Experimental Station (LGES), DLR's Optical Communications Availability, and KARI's Deep Space Antenna reports were used to understand basic communication needs and capabilities.
4. Promote the expansion of the Interoperability Plenary (IOP), Interagency Operations Advisory Group (IOAG), IOAG Space Internetworking Strategy Group (SISG), Space Frequency Coordination Group (SFCG), Consultative Committee for Space Data Systems (CCSDS), and to include all members of the ILN who desire membership;	✓ The IOAG has added BNSC (observer status) to join existing members ASI, CNES, DLR, ESA, ISRO, JAXA, and NASA. CSA and KARI may apply for membership. ✓ SISG membership includes CNES, DLR, ESA, ISRO, JAXA, and NASA. The ILN Comm WG co-chairs are both members and ensured that ILN needs were factored into SISG plans and communications roadmap. ✓ The ILN members all have direct membership in SFCG. ✓ ASI, BNSC, CNES, CSA, DLR, JAXA, and NASA have full membership in CCSDS while ISRO and KARI have observer membership.
5. Work with the SFCG to ensure that ILN spectrum needs are incorporated into SFCG recommendations;	✓ The SFCG was briefed on ILN's needs. The SFCG's Lunar/Mars Spectrum Coordination Group (LMSCG) agrees to work with ILN to ensure spectrum is coordinated.
6. Work with the SISG to ensure that the strategic plan supporting international interoperability recommended by SISG to the IOAG reflects the protocols and standards desired to support the ILN;	✓ The ILN Comm WG ensured that the SISG's report "Recommendations on a Strategy for Space Internetworking," 15 November 2008 includes scenarios submitted by the ILN Communication WG for interoperability.
7. Work with the IOAG to ensure that the strategic plan supporting international interoperability recommended by the SISG is adopted and recommended to the IOP;	✓ The SISG's report "Recommendations on a Strategy for Space Internetworking" was approved by the IOAG.
8. Work with the CCSDS to ensure that ILN standards and protocol needs are incorporated into CCSDS recommended standards;	✓ ILN scenarios and operations concepts were presented at the CCSDS Fall Conference in September 2008.
9. Work with the IOP to ensure that the strategic plan supporting international interoperability recommended by the IOAG is adopted; and,	✓ The SISG's report "Recommendations on a Strategy for Space Internetworking" was approved by the IOP.
10. Provide initial communications recommendations to the ILN Steering Group by December 2008.	✓ Recommendations are contained in this report and will be presented at the next ILN Steering Group meeting.

On the day of signing of the SOI by the participants, the Comm WG (Membership list: Appendix A) held one meeting. (The ILN Steering approved the WG charter which is contained in Appendix B. Ten subsequent teleconferences were conducted in the preparation of this report. All WG materials, such as presentations and meeting minutes, are available and will be posted online when an ILN web site is established. The Terms of Reference (Appendix B) for the ILN Comm WG were finalized on 28 July 2008 in accordance with the principle that it would focus on fully understanding the opportunities and advantages of the potential cooperation.

This report fulfills Objective 10 above and provides a status of the other objectives. Notably all objectives of the ILN Comm WG for the calendar year 2008 have been met. The ILN Comm WG will continue to meet in calendar year 2009 with the objectives identified in the draft ILN Comm WG TOR-2009 (Appendix C). This draft of the ILN Comm WG TOR-2009 is provided in order to document this group's proposed activities and achieve concurrence of the same among the ILN partners.

Conclusions of this preliminary phase of investigation are:

1. The organizations established to coordinate international use of spectrum (SFCG), standards (CCSDS), and operational cross support (IOAG and IOP) acknowledge ILN's needs and are prepared to continue collaboration to ensure the successful achievement of ILN's mission objectives.
2. No major spectrum issues were identified by the ILN Comm WG or SFCG.
3. The SISG's report "Recommendations on a Strategy for Space Internetworking," 15 November 2008 includes ILN communications scenarios for interoperability and was approved by the IOAG and IOP.
4. Preliminary ILN operations concepts and scenarios were developed to be consistent with CCSDS standards however technical evaluation of specific standards and options needs to be performed to confirm that interoperability is feasible for all ILN partners.
5. The desire for far-side nodes drives the need for a lunar-orbiting communications relay.
6. The desire to capture information from all the nodes over a full lunar cycle (6 years) drives the need to operate a lunar-orbiting communications relay for 6-10 years.
7. A lunar-orbiting communications relay would provide additional benefits to the ILN by reducing the communication payload requirements of the nodes and associated missions.
8. Multiple agencies have an interest in implementing a lunar relay and there are cost benefits of a multi-agency partnership for implementing such a lunar relay.
9. While near-side nodes could transmit their data directly to Earth at low data rates (kbps), a relay in a Low Lunar Orbit (LLO) making short passes would force far-side nodes to store ~175 MB and transmit at medium rates (up to 5 Mbps).
10. No Position, Navigation, and Timing (PNT) requirements have been identified that would drive the inclusion of special PNT capabilities in the ILN communications package or the development of new PNT technologies. However, timing requirements were not specifically addressed during this study cycle by this WG.

11. Since the NASA SDT determined that far-side ILN stations will not require LRRs, there does not appear to be any need for a laser ranging device on an orbiting platform. Hence, there does not appear to be any opportunity for synergy with NASA's optical communications technology development program.
12. Site selection criteria should consider terrain masking that constrains pass duration and latitudinal and longitudinal separation since a minimal relay capability may only be capable of servicing one ILN surface station at a time.
13. Optical communications links are an option for data relaying between lunar relay satellites, or lunar landers, and earth stations. An interlinked global optical ground station network would enable maximum throughput and reliability for such downlinks.

Recommendations for the ILN Communication WG in the next phase of investigation are:

1. Participate directly in the SISG's development of an implementation plan based on the "Recommendations on a Strategy for Space Internetworking";
2. Conduct a BNSC-NASA bilateral study of the potential for NASA to provide a communications payload for ILN use on BNSC's proposed MoonLITE mission;
3. Work with the SFCG's LMSCG to establish specific spectrum recommendations for ILN;
4. Conduct a study with NASA's Exploration Systems Mission Directorate on options for evolution of the lunar communications from robotic ILN support to robotic and human support;
5. The utility of an ILN relay should be discussed with the International Space Exploration Coordination Group (ISECG) and those agencies pursuing other lunar missions in addition to ILN;
6. On receipt of the report by the Core Instrument WG, conduct a pre-formulation study of options to meet the ILN communication needs based on emerging science requirements and potential ILN partner contributions;
7. Conduct a study to identify common communications practices for ILN missions;
8. Prepare preliminary communication requirements including alternate or prioritized sets of requirements if needed to address options identified by the Core Instrument WG;
9. Study the existing and planned CCSDS standards and recommend any changes needed to support ILN including: a) assessing the ability of ILN members to implement the minimum set of standards needed to conduct ILN missions; b) identifying impact to ILN member facilities to implement the minimum set of standards; and c) assessing technical and schedule changes to CCSDS plans if any to meet ILN needs;
10. Based on NASA's Commercial Lunar Communications and Navigation Study report and assess the potential for ILN use of a commercial communications service provider. ILN members should participate in the next phase of NASA's Commercial Lunar C&N Study;
11. Continue to identify ILN member ground and space assets that could be used to support ILN missions and work with the IOAG to update their data on these capabilities;
12. Support the ILN members in implementing the IOP resolutions that affect (or are affected by) ILN;

13. Study the impacts of landing sites on the far side or in permanently shadowed or polar craters on relay orbits, pass duration, and revisit frequency and the corresponding impacts on the design of landers and the surface-orbiter communications links.
14. Timing requirements were not specifically addressed during this study cycle by this WG and should be studied to determine those requirements, if any.
15. An implementation of common test beds to test cross support interoperability would be useful and should be investigated.
16. Coordination with the Site Selection WG should be done to refine communication requirements and the resulting cost and capabilities of the lunar relay.
17. Optical high speed downlinks should be considered as an important enabling technology for lunar and other exploration missions and international cooperation and standardization in this field should be fostered.

2.0 INTRODUCTION

The ILN initiative comes at an opportune time when international space agencies are focusing unprecedented resources on lunar exploration. In what the Planetary Society has termed "The International Lunar Decade" six different nations are planning to send as many as 18 orbiters and landers to the Moon in the coming years. The European Space Agency's (ESA) Small Mission for Advanced Research in Technology-1 (SMART-1) mission ended in 2006, and Japan's Kaguya and China's Chang'e-1 as well as India's Chandrayaan-1 are currently in orbit around the Moon. A series of orbiters, landers, and rovers from Russia, Germany, and the United Kingdom (UK), as well as Japan, China, and India will follow by 2015. NASA will launch the Lunar Reconnaissance Orbiter (LRO) this year, and the agency is planning several low-cost lunar missions for the following years. Overall, the Moon is currently the target of unprecedented international interest.

The Moon is very much an international arena and the ILN provides new opportunities for synergy among space faring nations. According to current plans the nodes of the ILN will be built and launched by different space agencies, but their landing sites on the Moon will be coordinated in advance according to the needs of the network. This will allow the network as a whole to monitor geophysical activity over the entire Moon. Each of the nodes will carry a core set of ILN defined instruments as well as instruments unique to each station. The unique instruments in each station will vary, and as such, allow the stations to carry out scientific measurements independently of the ILN.

Some of the instrument categories that are being considered for the ILN, such as seismic monitors and LRRs, were placed on the lunar surface in the past by the Apollo astronauts and various robotic landers. But modern instruments are far more sensitive and accurate than those designed and built 30 and 40 years ago. In addition, new scientific investigative areas that are now open may drive new requirements on sensors and communications. In particular, no instruments were placed on the far side of the Moon, where communication with Earth required the presence of an orbiter or relay system. In contrast, the ILN will be designed specifically to monitor the entire Moon, and some nodes will be placed on the Moon's far side. From the onset of the ILN, it has been recognized that some nodes of the network should be located on the lunar far side in order to enhance the scientific value of the ILN data set. In support of this realization, NASA plans to study options for a lunar communications relay satellite or relay package as a secondary payload capability as part of its contribution to the ILN endeavor. The UK also has a strong interest in studying the architecture of possible lunar communications infrastructure.

The ILN Comm WG was formed to specifically examine the transmission of data as well as tracking, ranging, and timing requirements associated with the core instruments of the ILN network and the collateral capabilities of its partners in addressing those requirements. The Comm WG addressed the objectives assigned to it for the calendar year 2008 and provides the results of its work with this report.

3.0 COMMUNICATION AND NAVIGATION (C&N) NEEDS

The communication and navigation requirements of the ILN will be mainly driven by the capabilities of the ILN node instruments defined by the Core Instrument WG. The following subsections provide an overview of the ILN science goals and a review of the resulting node instruments capability for their communication and navigation requirements.

3.1 Science

The Moon preserves a record of geologic processes of early planetary evolution in our solar system and holds a unique place in the evolution of rocky worlds. The crust has never been altered by plate tectonics (such as what happens on the Earth), planet-wide volcanism (Venus), or wind and water (Mars and Earth). Moon rocks originated through high-temperature processes with no involvement with water or organics, yet the Moon and Earth are related and formed from a common reservoir. In addition, the lunar surface has been exposed to billions of years of volatile input and offers a completely different direction of scientific investigation. Many fundamental concepts of planetary evolution were developed using the Moon but it is clear that much more can be discovered.

The goal of the ILN is to understand the interior structure and composition of the Moon. This goal should be realized by obtaining the following information:

- Determine the size, composition, and state (solid/liquid) of the core of the Moon.
- Characterize the thermal state of the interior.
- Characterize the workings of the planetary heat engine.
- Characterize the chemical/physical stratification in the mantle, particularly the nature of the putative 500-km discontinuity and the composition of the lower mantle.
- Determine the thickness of the lunar crust (upper and lower) and its lateral variability on regional and global scales.

Many, if not all, of the fundamental questions about the structure of the lunar interior can be met with the following measurements:

- Seismometry
- Heat flow
- Electromagnetic (EM) sounding

- Ranging

It is believed that the baseline goals of the ILN can be achieved using these four complementary geophysical analyses at each of the 6-8 locations on the Moon, operating simultaneously and continuously for one lunar tidal cycle (6 years).

The full extent of the science requirements that were available for this phase of ILN Comm WG analysis are discussed in the NASA SDT Final Report.

3.2 Communications and Navigation

Based on the science requirements identified by the SDT that include the need to support far-side landers, ILN will require several types of communications links:

- Surface to/from Earth, i.e., Direct-To-Earth (DTE) and Direct-From-Earth (DFE);
- Earth to/from Orbiter; and
- Orbiter to/from Surface.

Depending on the mission concepts developed by the ILN partners, other types of links may also be needed:

- Orbiter to Orbiter, e.g., for inter-spacecraft range-rate or for crosslinks; and/or
- Surface to Surface, e.g. base station to a rover.

In this section, communications is discussed in terms of the following categories:

- Science Data
- Command and Telemetry (i.e., housekeeping data)
- PNT including tracking
- Additional Sources of Requirements

Following this, two special but related topics are discussed:

- Orbit for Communications Relay, and
- Site Selection Criteria.

3.2.1 Science Data

Table 3.1 contains information extracted from the NASA SDT report on the types of measurements needed for the proposed core instruments, other key driving characteristics needed for the ILN network, and the derived implications on the instruments' capabilities, data rates, and other factors driving the communications infrastructure needed to support ILN.

Using rough calculations without including margins, assuming the worst case EM sounding data volume of 100 Mbits/day, and assuming that the heat flow sensor data volume taking one measurement per 6 hours is negligible in comparison, leads to an estimate of ~200 Mbits/day for the data volume per ILN surface station. This equates to an average data rate of less than 2400 bps—a very low data rate if these stations were connected to a terrestrial local area network.

Table 3.1—ILN Science Measurements and Communications Needs (Source: NASA SDT)

Type of Measurement	Requirements
Seismometry	• Three-axis VBB (Very Broad Band) seismometers with dynamic range of ~ 24 bits • Inter-station timing accuracy of order milliseconds • Global distribution (far side coverage; highland, mare and Procellarum Potassium-Rare Earth Element-Phosphorus (KREEP) Terrane (PKT) locations; greater than Apollo's ~1000 km spacing • 100 Mbits per Earth day continuous; no downlink drivers
Heat flow	• Three primary options: DLR Mole, Drill (various commercial providers), or Penetrator (e.g., MoonLITE) • Thermal gradient dT/dz: monitor temperature in a 3-m array • Minimum 9 thermal conductivity measurements and 9 temperature measurements • Continuous monitoring every 6-12 hours for 2 years
EM sounding	• Multiple single-station EM soundings up to 100 Hz • Three electrometers to measure orthogonal components of electric field; two magnetometers to mitigate lander interference • 10-100 Mbits per Earth day continuous; no downlink drivers
Ranging to LRR	• <2 cm range accuracy for measurements done from Earth • New arrays on the lunar near side placed >90° from Apollo arrays • Passive; 0 bits per second • Can also be used to test laser communication systems under development (high bandwidth links) – Possible interest to NASA Space Operations Mission Directorate
ILN Network Characteristics	**Requirements**
Number of nodes	• The more the better! • 4 = minimum number to detect lateral variation in the deep interior structure; possibility of localizing shallow moonquakes (depending on geometry)
Lifetime requirement	• Science Baseline: Understand the interior structure and composition of the Moon using these four complementary geophysical analyses at each of 4 locations on the Moon, operating simultaneously and continuously for one lunar tidal cycle (6 years) • For baseline (4 nodes)—need to observe and localize a sufficient number of strong, shallow earthquakes to understand their location and mechanism they occur randomly over the globe—one lunar tidal cycle should have ~6 • 28 recorded shallow moonquakes (~1 magnitude 5 or greater event per year)
Site selection	• Many active moonquake nests exist, but desire for far side information means either the source or the stations must be on the far side • Approximate sites for first 2 nodes: Station 1: -5°S, 75°W; Station 2: 30°N, 75°E • Also involves desires from engineering for Delta velocity or change in velocity (ΔV) and comm • 2 nodes at poles have serious science drawbacks • International partners may well end up at a pole for their own exploration/research

However, buffering the data for a far-side station serviced by a lunar relay making one overhead pass per week (worst case gap) from a LLO results in the need for the ILN node to store ~175 MB. For a 10 minute pass by the relay assuming a 15° terrain mask, the ILN station would need to transmit ~2.4 Mbps ignoring protocol overhead, retransmissions due to errors, data from other science instruments, and other factors.

A previous (unpublished) study done by NASA showed that terrain masking at certain sites with high scientific interest such as South Pole-Aitken Basin could have worst case terrain masking up to 25-30°. This would reduce the pass time by up to 50% and double the required data rate to 4.8-5 Mbps. Thus, limiting the availability of the relay to a secondary payload on an orbiting platform such as a penetrator dispenser could drive up the data transmission rate on the surface station a thousand fold.

3.2.2 Command and Telemetry

Lunar lander concepts from all members are for small, simple, relatively low cost vehicles with a small complement of science instruments. The data rate needed to command and control these landers is anticipated to be low, i.e., in the 2-4 kbps range. Similarly, telemetry from lander subsystems (separate from the science data) should also be less than 10 kbps. These capabilities can be met by several existing CCSDS standards. Thus, no technology or standards development should be needed. Interoperable command and telemetry capabilities should be achievable enabling cross support between ILN partners.

3.2.3 Position, Navigation and Timing (PNT)

PNT considerations for ILN assume that the lunar gravity model is improved by the Kaguya, LRO, Chang'e-1, and Chandrayaan-1.[3] LRO combines Laser Ranging (LR) with 10 cm range precision, the Lunar Orbiter Laser Altimeter (LOLA) with 10 cm range accuracy and S-band tracking. "From a combination of LR, altimeter, and S-band tracking we estimate positional accuracies of ~25 m along track[1] and ~0.5 m radially … after improvement of the lunar gravity field." The result will be "We can expect to know distances and locations of lunar features to 25 to 50 meters horizontally (~50 to 70 meters from LRO) and 1 meter radially, in a center of mass system. Gravity could be adequate for landing at identified locations to within ± 50 meters." [4]

The Gravity Recovery and Interior Laboratory (GRAIL) mission will provide data for further improvements. GRAIL is using a Ka-band Lunar Gravity Ranging System (LGRS) derived from the Gravity Recovery and Climate Experiment (GRACE) mission's instrument to measure the inter-spacecraft range-rate. This LGRS could be a candidate for use on a communications relay providing both 32 GHz (gigahertz) communications compatible with the DSN and inter-spacecraft range-rate measurements to any future lunar mission carrying a similar capability.

The ILN Comm WG has not identified any need for orbit determination or landing accuracy greater than the capability planned to be available as a result of these precursor missions. Our preliminary conclusion is that no additional PNT requirements have emerged that would drive the inclusion of special PNT capabilities in the ILN communications package or the development of new PNT technologies.

The ILN Comm WG considered the implications of the initial assertion that all ILN landers would carry the same core instruments. The LRRs on near-side landers can be used by any of the Earth sites in the International Laser Ranging Service (ILRS)[2] as well as other partner facilities. However, LRRs on far-side landers would have to be lased from an orbiting platform. This might impose a requirement on the communications relay for a dual purpose optical communications and ranging device. When asked, Dr. Barbara Cohen, the ILN SDT Co-chair from NASA Marshall Space Flight Center (MSFC), responded that ranging on an Earth-spacecraft-lunar surface path would require precision on the order of 1 cm or less which has not been studied. However, far-side LRRs would not be "more or differently useful than a couple of new near-side

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[1] Average Root-Sum-Square (RSS) position error

[2] ILRS web site: http://ilrs.gsfc.nasa.gov

assets." The reason is that "the issue at this point is that you need more stations and more measurements to be able to deconvolve the multiple different contributions because the measurement uncertainty is still high compared with the source motions."[6]

On this basis, the WG concludes that:

- LRRs are not required on far-side ILN landers; and
- Lasers for ranging are not required as part of the communications relay capability.

It was noted by the Comm WG that Timing requirements were not specifically addressed during this study cycle and should be studied to determine those requirements, if any.

3.2.4 Additional Sources of Requirements

While not a requirement related to the geophysical network, some or all of the ILN partners may desire to send video images such as low rate or low resolution imagery (e.g., "web camera" quality) for purposes of Education and Public Outreach (EPO) including publicity. This has not been factored into the WG's estimates of data volume but should be assessed further in the next phase of studies.

Due to the need for a relay, the ILN can be used right from the initial period as a risk reducer and precursor for C&N technology and services that will be built up to support lunar science and exploration missions that have a high data rate, specifically, the Human Exploration phase beginning in 2020.

The WG recommends that the utility of an ILN relay be discussed with the ISECG and those agencies pursuing other lunar missions in addition to ILN.

3.2.5 Orbit for Communications Relay

The preliminary scientific definition for a geophysical network envisions continuous operation for 6 years. If the ILN network consists solely of near-side landers, then Earth ground stations are sufficient to address the required mission duration. Since the SDT recommends including far-side landers, an orbiting relay capability matching the 6 year continuous operation period is needed. Knowledge of lunar orbits from prior missions shows that LLO such as the 50-100 km circular orbits used by most science missions are highly unstable and require significant propellant for orbit maintenance. For mission durations of 0.5-2.0 years, this may be acceptable. For ILN, this drives the size and mass of the propulsion system up to the point where trade studies between maintaining the LLO requiring a large propellant load versus boosting the platform carrying the relay to a higher, more stable orbit with longer passes.

The ILN Comm WG did not study specific orbits during this phase. Relay orbits should be studied that provide higher altitudes for longer pass times and more frequent revisits to reduce the burden on landers. For options that include the relay capability on a LLO platform such as MoonLITE and SELENE-2, this should include analysis of boosting the platform to a higher orbit after the initial purpose of the platform, e.g., deployment or science, is accomplished.

3.2.6 Site Selection Criteria

Keeping the design of ILN stations and the orbiting relay as simple as possible dictates that site selection criteria include the following considerations:

- The minimal design of an ILN relay will only be capable of servicing one ILN surface station at a time. The relay may be able to simultaneously receive data from the lander and transmit it to Earth or operate during portions of the far side in a store-and-forward mode. To accommodate the duration of relay passes and the relay's orbit, lander sites may be constrained in both latitudinal and longitudinal separation.
- Sites should consider terrain masking as a factor that limits pass duration and drives up the communication data rate.
- While the NASA SDT determined that polar sites were not recommended for investigation of the lunar interior structure and composition, several partners are interested in investigating permanently shadowed polar craters. These craters impose terrain masking constraints as well as constraining the relay to include polar or highly inclined orbits.

4.0 ILN CONCEPTS OF OPERATION

This section shows concepts on how elements on or around the Moon can be operated using various communications links and communications services. The concepts described in this section were coordinated with the SISG and inserted into their report "Recommendations on a Strategy for Space Internetworking," 15 November 2008.[7] This report was approved with modifications by the IOAG on 10 September 2008 as Resolution R12.11.1. On 10 December 2008, the IOP-2 accepted the IOAG's recommendations and directed the IOAG to formalize the result in Resolution #6 of the Joint Communiqué:

> *"The IOAG's Space Internetworking Strategy Group (SISG) should formalize a draft Solar System Internetwork (SSI) Operations Concept and candidate architectural definition in time for IOAG-13 and should prepare a mature architectural proposal for review and endorsement at the third Inter-Operability Plenary meeting (IOP-3). At that time, the IOAG is requested to present an enhanced service catalog for endorsement. The IOP Agencies should ensure representation from their programs and projects to work with SISG to identify potential missions which may benefit from adoption of the SSI-related standards, leading to a gradual build up of in-space and ground-based space internetworking infrastructure."*

IOAG-13 is scheduled for September 2009.

4.1 Initial Period: Single Missions

Before interoperable communications services are deployed to support lunar missions, each lunar mission has to use only communications resources owned by the agency that launched the mission. There are two cases concerning how communications between an element on or around the Moon and the ground are performed. In the first case, a direct-to-Earth link is used without any relaying satellite. In the second case, a communications relay satellite orbiting around the

Moon is used to relay communications between the user element and the ground. To support elements landed on the far side of the Moon, the second case must be used.

An example of this scenario is depicted in Figure 4.1. In this case, Agency A has a lunar lander but it has to use a relaying lunar orbiter and a ground station owned by itself to support communications with the lander. Agency B has a lunar lander, too, but it also has to rely on communications resources that it owns.

4.2 Full Network

When interoperable services are available to support lunar missions, a lunar mission of one agency can be supported by communications resources of another agency (or other agencies).

Some examples of this kind of scenario are shown in Figure 4.2 through Figure 4.4. All of these examples are for a case in which a landed element of one agency is supported by communications resources owned by another agency. Figure 4.2 shows a scenario in which the lander uses a direct-to-Earth communications link to communicate with a ground station of the supporting agency. The ground station communicates with the control center of the lander through the network control center of the supporting agency, but the ground station can alternatively communicate with the lander control center directly. Figure 4.3 is a case in which the lander communicates with the ground through a relaying orbiter of the supporting agency. In this case, the relaying orbiter communicates with the lander control center through a ground station and the network control center of the supporting agency. Figure 4.4 is also a case in which the lander communicates with the ground through a relaying orbiter of the supporting agency. In this case, however, the relaying orbiter communicates with a ground station of the supported agency.

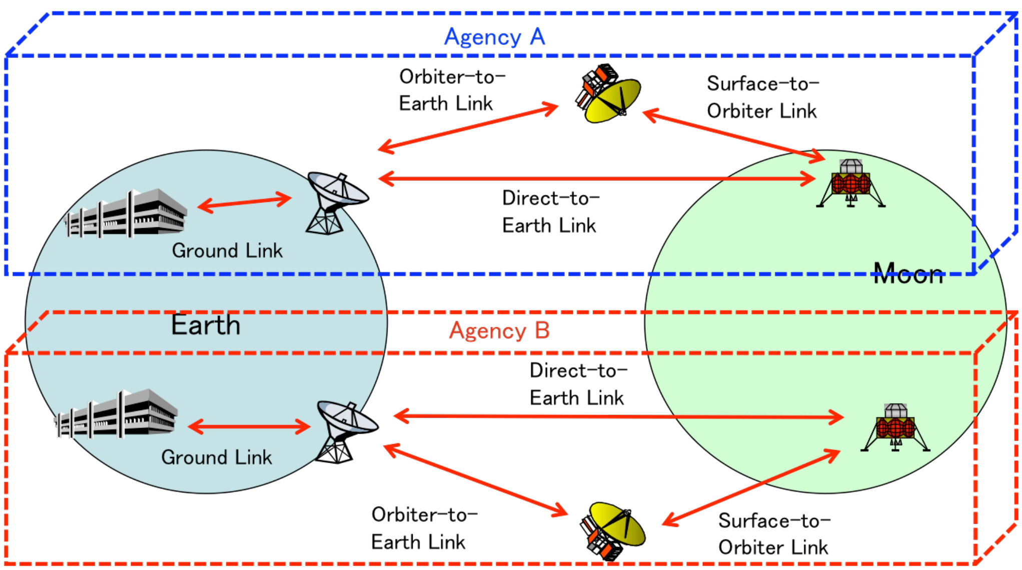

Figure 4.1—Single Missions

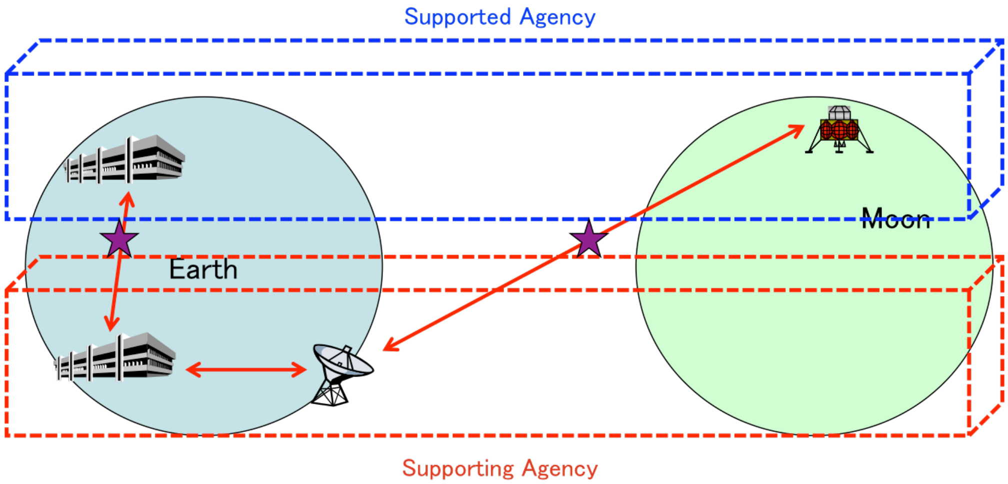

Figure 4.2—Direct-to-Earth Interoperability

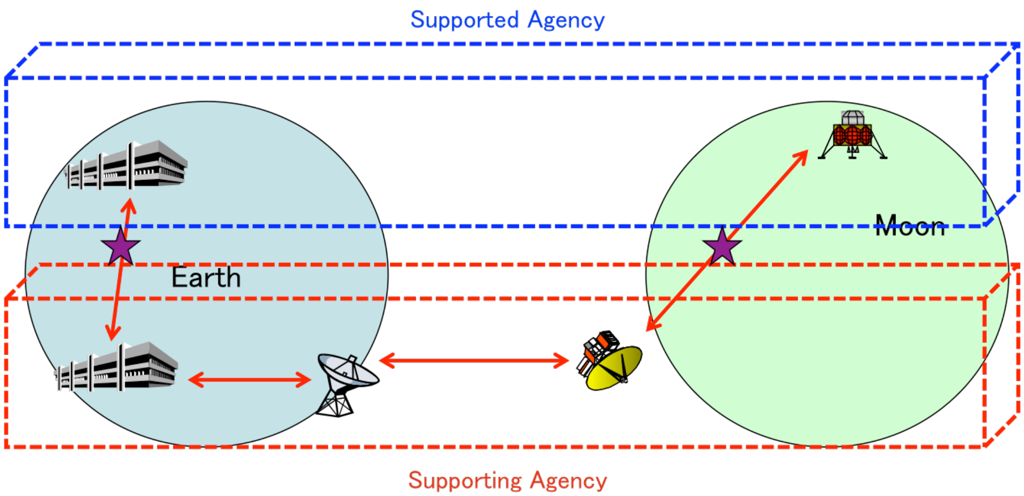

Figure 4.3—Orbiter Interoperability

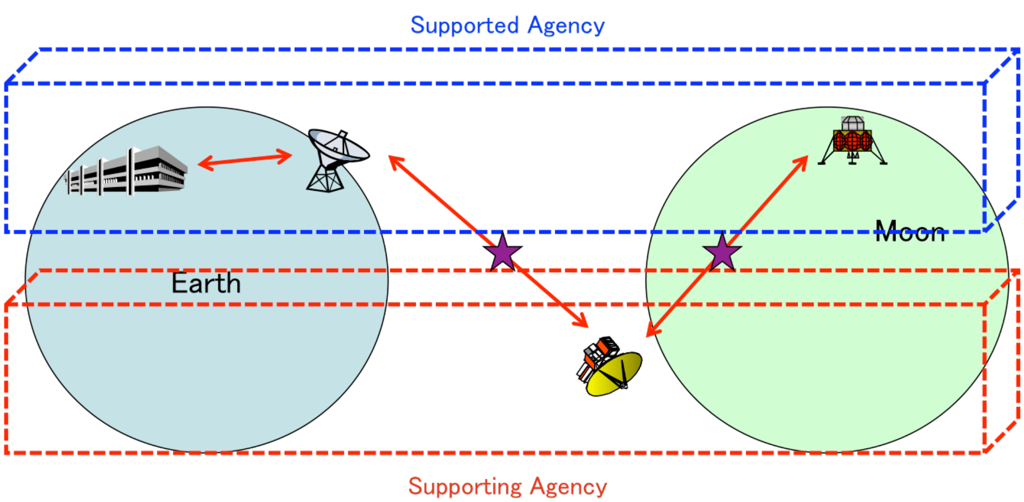

Figure 4.4—Orbiter and Ground Interoperability

4.3 Evolution of ILN From Robotic to Human Mission Era

In the human lunar mission era, there will be various elements of multiple agencies on the surface of the Moon cooperating with each other in a variety of ways. For example, there will be a lunar base built by Agency A with astronauts from Agencies B and C and rovers from Agencies D and E, and so on, all of which participate in communications with some other elements in various ways.

Figure 4.5 shows a communications scenario that may occur in this era. In this example, a rover of one agency is supported by a lunar base, a relaying orbiter, a ground station, and the network control center of the supporting agency. This is just one of the many possible communications scenarios that will be utilized in the human mission era.

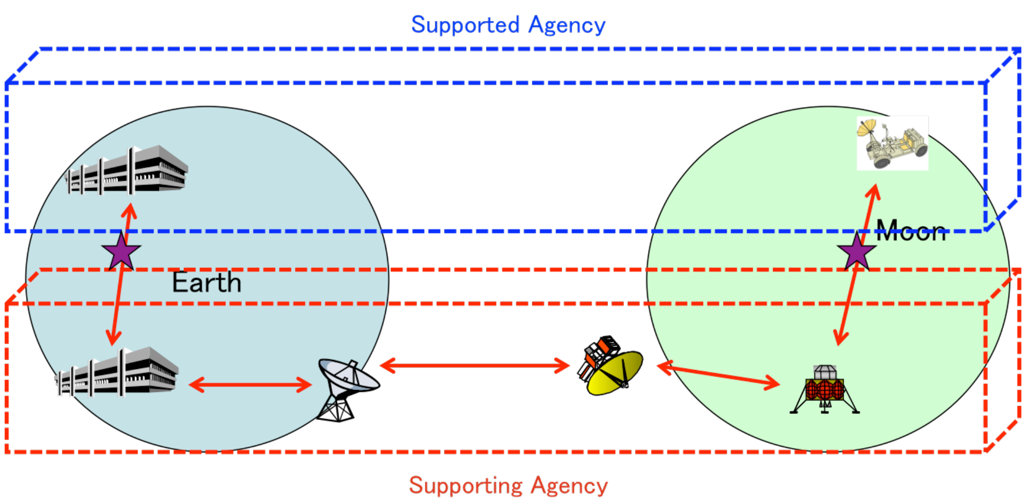

Figure 4.5—Lunar Surface Interoperability

5.0 INTEROPERABILITY

This section explains how Agencies can cooperate in the ILN by using C&N protocols and services at various interoperability points. As with Section 4.0, the interoperability information in this section was incorporated into the SISG's report "Recommendations on a Strategy for Space Internetworking"[7] and approved by the IOAG and IOP-2.

5.1 Overview—Interoperability Points

Interoperability is the technical capability of two or more systems or components to exchange information and to use the information that has been exchanged. A point at which two or more systems or components exchange information is called an interoperability point. Figure 4.2 through Figure 4.5 show cases where interoperability is used to support lunar missions. In these figures, interoperability points are shown with purple stars. Interoperability points correspond with interfaces that cross agency boundaries.

For each of the interoperability points, a set of interface conditions must be agreed on by the agencies at both ends of the interface. This set of interface conditions will include the following:

- Spectrum Environment

- Communications Protocols
- Navigation Protocols
- Networking Protocols

Preferably there should be a multilateral agreement on the set of interface conditions that are used by all the participating agencies for each type of interoperability points (for example, lunar surface interoperability points, surface-to-orbiter interoperability points, direct-to-Earth interoperability points, ground interoperability points) so that any element of any agency can participate in communications without any extra negotiation on the interface conditions.

5.2 Spectrum Environment

The SFCG LMSCG is responsible for maintaining the Lunar and Martian Spectrum Plans. The spectrum usage of the ILN related missions are expected to conform to the spectrum plan usage and agreements reached by the agencies through the activities of the SFCG and in particular with those activities of the LMSCG. The most recent spectrum plans are available on the SFCG web site under password protection.[8]

Using the mission models maintained by the IOAG, together with the planned frequency bands and data rate information obtained from the Mission Data forms gathered at the Lunar/Martian Technical Meetings held in 2006, it is possible to look for commonality in frequency planning among agencies. Several examples of common band usage were found and can be seen in Table 5.1 for the lunar missions. Table 5.1 explains the color coding found in the Frequency Plan Figures that follow.

The first requirement of interoperability is for agencies to use the same frequency bands for similar functions. Table colors only indicate the *possibility* of interoperability. For true interoperability to exist, several other parameters, such as modulation types, signal levels, and to some extent, data formats must also be compatible. In these tables, **Green** reflects a similar usage in the frequency band by several LMSCG member agencies meaning that there is a potential for interoperability. Although only one agency may be using the band at this time, **Green** also indicates a general agreement among other agencies to do so in the future. **Blue** is applied to bands used by fewer agencies and for those bands where specific technical or regulatory issues were identified, but that still may be used for interoperability if relevant issues are resolved. Bands identified for use by only one agency are in **Orange.** At this juncture interoperability discussions would be pointless. Finally, **Red** is used for bands, which may offer the potential for interoperability at some future date, but where no proper technical discussion was possible at this time.

In the following tables, the names of agencies planning to use each of the Forward and Return link bands are shown along with the frequency allocation.

The most heavily used space-to-Earth bands are the Category A mission 2- and 8-GHz bands and the Category B mission 8-GHz band. Readers will note that these are **Green**. For direct-to-Earth links, there are relatively few **Orange** or **Red** colored bands, most are shown in **Green** or **Blue**.

The LMSCG has also developed additional tables reflecting Space Research Service missions that are not in the vicinity of the Moon. These tables have been developed because missions in these other locations also must share frequency bands with the Lunar Missions.

The lunar far-side surface offers, at least in the early stages of lunar development, protected radio-quiet sites that could enable efficient use of highly sensitive radio telescopes and instrumentation. The International Telecommunication Union (ITU) has formally recognized the scientific importance of lunar radio astronomy and notes that the low level of radio interference in this zone could be compromised by noncompliant lunar activities on the far-side surface, in lunar orbit, or by science missions elsewhere. In consideration of this, strategies such as the use of high-performance optical communications may minimally compromise the scientific resource environment on the far side of the Moon.

Table 5.1—Lunar Vicinity Frequency Plan

Band	Forward	Agency	Return	Notes
Operational direct from/to Earth				
S-Band	**2025-2110 MHz**	All	**2200-2290 MHz[5]**	
X-Band	**7190-7235 MHz**	Roskosmos ESA ISRO JAXA CNSA	**8450-8500[1] MHz**	
Ka-Band	**22.55-23.55[2] GHz**	NASA DLR[a] JAXA[b]	**25.5-27 GHz[3]**	[a]Narrowband Ranging [b]Downlink only[8]
Lunar Relay Trunk Line				
Ka-Band	**40-40.5 GHz**	NASA	**37-38 GHz[7]**	
Lunar relay to/from Orbiter or Surface Orbiter to/from Surface Orbiter to Orbiter				
UHF	**435-450 MHz[4]**	JAXA ISRO	**390-405 MHz[4]**	
S-Band	**2025-2110 MHz**	NASA JAXA	**2200-2290 MHz[5]**	
Ka-Band	**22.55-23.55 MHz**	NASA	**25.5-27 GHz[3]**	
Surface to Surface [6]				
UHF	**410-420 MHz**	NASA	**410-420 MHz**	Under study
IEEE 802	**868-915 MHz, 2.4 GHz**	NASA	**868-915 MHz, 2.4 GHz**	Under study
Lunar Relay to Lunar Relay Cross Link				
Ka-Band	**37-38[7] GHz**	NASA	**40-40.5[7] GHz**	Reverse Band
Ka-Band	**22.55-23.55 GHz**	DLR	**25.25-27.5 GHz**	Under study for subsatellite ISL
Ku-Band	**13.75-14 GHz**	DLR	**14.5-15.35 GHz**	Under study for subsatellite ISL

Used by many. Agreed. Interoperability possible.
Used by many. Agreed. Interoperability potential. Discussion on sharing the band.
Used by one agency (no interoperability needed at this stage). Agreed
Still to be discussed.

1. SFCG Recommendation 5-1R5 limits individual mission bandwidths to 10 MHz.
2. A new allocation for at least 500 MHz Space Research Service (SRS) uplink spectrum is required.
3. Coordination is required among all different users of the band: SRS for lunar missions, SRS for non-lunar missions, Earth Exploration-Satellite Service (EESS). The specific issue of manned mission protection criteria will be discussed at SFCG.
4. The ability to share these lunar surface bands with Earth-based radars needs to be confirmed.
5. Suitable for interoperability, but the band needs to be used wisely, since it is widely used for nearly all the space missions including low Earth orbit missions. Application of the SFCG Resolution 24-1 is necessary (6-MHz bandwidth limit and no emission when it is not necessary to transmit).
6. Band selection under study.
7. Utilization of these bands are subject to SFCG Recommendation 14-2R5. Also, these bands are not allocated for Intersatellite Service crosslinks (ISLs).
8. Planned implementation no sooner than 2018.

5.3 Communications Protocols

The following table shows candidate communications protocols to be used for each of the interoperability points shown in Figure 4.2 through Figure 4.5.

Table 5.2—Candidate Communications Protocols

Interoperability points	Physical protocols	Data link protocols	Other protocols
Surface	IEEE 802.x	IEEE 802.x	
Surface-to-orbiter	Proximity-1 Space Link Protocol*	Proximity-1 Space Link Protocol*	
Orbiter-to-Earth, Direct-to-Earth	RF and Modulation Systems*	TC/TM/AOS Space Data Link Protocols* TC/TM Synchronization and Channel Coding*	
Ground	Various	Peer to Peer Protocol (PPP), etc.	Space Link Extension (SLE)*, TCP/IP
*CCSDS standards			

The protocols with an asterisk are standard protocols recommended by the CCSDS. Most of these protocols have been used by many space projects in the world, and interoperability among various communications resources belonging to different agencies using these protocols has been proven. Therefore, these protocols are the primary candidates for interoperable communications protocols for future lunar projects. However, care should be taken to make sure that they meet the communications requirements of the ILN. There may be cases where modifications or extensions to these protocols need to be made so that they can meet the requirements. The first step for protocol selection should be analysis of communications requirements of the projects' ILN nodes and supporting communications assets (such as ground stations that need interoperability).

On space links, CCSDS has two sets of recommendations: one is primary for long-haul space communications and the other is for proximity communications. The CCSDS Recommendation for radio frequency (RF) and Modulation Systems recommends methods related to the physical waveforms (i.e., the Physical Layer) to be used on long-haul space links. CCSDS has three similar but slightly different Recommendations for the Data Link Layer, which are called the TC (telecommand), TM (telemetry), and AOS (Advanced Orbiting Systems) Space Data Link Protocols. They specify standard data units and standard procedures for processing data units. The basic data units for these protocols are called TC, TM and AOS Transfer Frames, respectively. The CCSDS Recommendations on TC and TM Synchronization and Channel Coding specify methods for synchronizing and coding Transfer Frames (TC Synchronization and Channel Coding should be used with TC Space Data Link Protocol, and TM Synchronization and Channel Coding should be used with TM or AOS Space Data Link Protocol).

5.4 Navigation Protocols

All of the protocols and standards shown above are CCSDS standards. Most of them have been used by many space projects in the world, and interoperability among various tracking and navigation resources belonging to different agencies using these protocols and standards has been proven. Therefore, these protocols and standards are the primary candidates for interoperable navigation protocols and standards for future lunar projects. However, care should be taken to make sure that they meet the navigation requirements of the future lunar projects. There may be cases where modifications or extensions to these protocols and standards need to be made so that they can meet the requirements. The first step for protocol selection should be analysis of navigation requirements of the ILN nodes and supporting navigation assets (such as orbit determination facilities) that need interoperability.

Table 5.3 shows candidate navigation protocols and standards that can be used for ILN.

All of the protocols and standards shown above are CCSDS standards. Most of them have been used by many space projects in the world, and interoperability among various tracking and navigation resources belonging to different agencies using these protocols and standards has been proven. Therefore, these protocols and standards are the primary candidates for interoperable navigation protocols and standards for future lunar projects. However, care should be taken to make sure that they meet the navigation requirements of the future lunar projects. There may be cases where modifications or extensions to these protocols and standards need to be made so that they can meet the requirements. The first step for protocol selection should be analysis of navigation requirements of the ILN nodes and supporting navigation assets (such as orbit determination facilities) that need interoperability.

Table 5.3—Candidate Navigation Protocols

Purpose	Protocols or Standards
Radiometric	**RF and Modulation Systems**
PN Ranging	Pseudo-Noise (PN) Ranging Systems
Time correlation/transfer	Proximity-1 Space Link Protocol
Orbit information exchange	Orbit Data Messages (ODM))
Tracking data exchange	Tracking Data Message (TDM)
Attitude data exchange	Attitude Data Messages (ADM)

The CCSDS Recommendation on RF and Modulation Systems has some specifications related to the characteristics of radio metric measurements. The PN Ranging System specifies methods for transparent and regenerative PN ranging systems. The Proximity-1 Space Link Protocol specifies timing services that provide the following three capabilities:

1. On-board Proximity clock correlation between Proximity nodes;
2. Time transfer to a Proximity node;
3. Coupled noncoherent time-derived ranging measurements between Proximity nodes.

The Orbit Data Messages (ODM), Tracking Data Message (TDM), and Attitude Data Messages (ADM) Recommendations specify standard message formats for use in exchanging spacecraft orbit information, spacecraft tracking data, and spacecraft attitude information, respectively.

5.5 Networking Protocols

There are three candidate networking protocols for future lunar projects: Space Packet Protocol (SPP), Internet Protocol (IP) and Delay Tolerant Networking (DTN).

The SPP is a CCSDS standard for transferring space application data over a network that involves a ground-to-space or space-to-space communications link. The basic data unit used by this protocol is called the Space Packet. This protocol has been used by many space projects in the world, and interoperability among various communications resources belonging to different Agencies using this protocol has been proven to some extent, but there are still some standards missing for projects to be fully interoperable using this protocol (e.g., an SLE service to transfer Packets (see Section 5.3).

IP is a standard networking protocol used in the Internet. Although there are not many space projects that have used it in space, many applications that run on top of IPs (i.e., Transmission Control Protocol (TCP)/IP and User Datagram Protocol/IP(UDP)/IP) can be used in space if IP is used as the networking protocol in space.

DTN is a protocol being developed by the Internet Research Task Force (IRTF) and CCSDS. It is primarily developed for links with delay and/or discontinuity. There is no space project that has used DTN for operational purposes, but NASA conducted an experiment in 2008 to demonstrate the use of DTN in deep space environment using the Deep Impact spacecraft.

Table 5.4 shows major features of these protocols.

Table 5.4—Candidate Networking Protocols

Protocol	Scope of Communications	Pros and Cons
Space Packet Protocol	Used for switched circuit communications. Can be used by applications connected by a pre-determined route.	+ Existing infrastructure supports space packets on point-to-point links - Limited addressing capability; no protocols or ops concept for cross-supported circuit services; no support for automated circuit management
Internet Protocol	Local to a particular well-connected and low-delay network component. Can be used by applications separated by multiple network ops but that have contemporaneous end-to-end connectivity and low latency.	+ Terrestrial IP mature; network-layer addressing; mature support for dynamic routing; end-to-end protocol - No ops concept for in-space cross-supported network service; issues in delayed/disrupted environments; infrastructure needs to be extended for IP service.
Delay Tolerant Network	Routed throughout the Solar System Internetwork. Can be used by applications regardless of latency or intermittent connectivity.	+ Addresses delayed/disrupted environments; network-layer addressing; emerging support for dynamic routing; end-to-end protocol - No ops concept for in-space cross-supported network service; less mature than IP; infrastructure needs to be extended for DTN services.

6.0 ILN CANDIDATE MISSION MODEL SET

The ILN will be the work of many nations and agencies, many of whom have only recently joined the community of spacefarers. As previously mentioned, in addition to the proposed ILN mission set the, international space faring community has undertaken many lunar missions.

6.1 ASI MAGIA

MAGIA (**M**issione **A**ltimetrica **G**ravimetrica geoch**I**mica lun**A**re) is a project funded by ASI in the framework of small satellite mission studies. MAGIA Phase A study has been recently completed and its outcome is under evaluation.

6.1.1 MAGIA Scientific Objectives

The goals of the mission can be summarized as follows:

- Detailed study of the internal structure of the Moon through its gravity and figure
- Study of the polar and subpolar regions in terms of their morphology and mineralogy
- Study of the lunar exosphere and radioactive environment

Further experiments will be carried out to study specific aspects of the fundamental physics, namely:

- Improved measurement of the gravitational redshift
- Precursor test for second generation Lunar Laser Ranging
- Determination of the position of the seleno-center

Table 6.1—MAGIA Payload Overview

Instrument	Measurement	Exploration Benefit	Science Benefit
CAM_SIR—Infrared spectrometer and context camera	24- to 6-m resolution mapping of surface mineralogical composition	Detection of surface ice, assessment of mineral resources of the Moon	Improved understanding of the geologic evolution of the Moon
RASCAL—Radar altimeter, radiometer and scatterometer	<1 m resolution altimetry, microwave emissivity, and backscattering coefficient	Topography and small-scale roughness for landing site characterization	Improved understanding of the internal structure of the Moon
ALENA—Energetic neutral atoms detector	Flux and velocity of neutral atoms and particles	Characterization of the space environment around the Moon	Improved understanding of the interaction between solar wind and lunar surface
Radio Science Payload	cm-precision ranging between Earth and spacecraft	Improved knowledge of the spacecraft trajectory in the Moon gravity field	Improved understanding of the internal structure of the Moon
CARISMA—High-resolution camera	2-m resolution imaging of the surface of the Moon	Surface characteristics for landing site characterization	Improved understanding of the geology of the Moon and of the cratering history of the solar system
VESPUCCI—CCR array for laser ranging	Test of accurate ranging between Earth and Moon	Improved knowledge of the spacecraft trajectory in the Moon gravity field	Precursor for general relativity experiment
RADIO—Energetic particle spectrometer	Flux of protons, neutrons, alpha particles, electrons	Safety from radiation for human explorers	Radiation conditions outside the Earth's atmosphere
ISA—Accelerometer	Measurement of non-gravitational forces acting on the spacecraft	Characterization of forces affecting the attitude of spacecrafts around the Moon	Improved understanding of the internal structure of the Moon

6.1.2 MAGIA Mission Overview

As shown in Figure 6.1, the MAGIA system will consist of

- Spacecraft: Satellite and subsatellite
- Ground and User Segments for mission control, operations, mission data archiving, and processing and distribution

- Support facilities for specific experiments (e.g., laser tracking and Radio Science stations); their usage is limited to fixed time slots and shareable with other projects

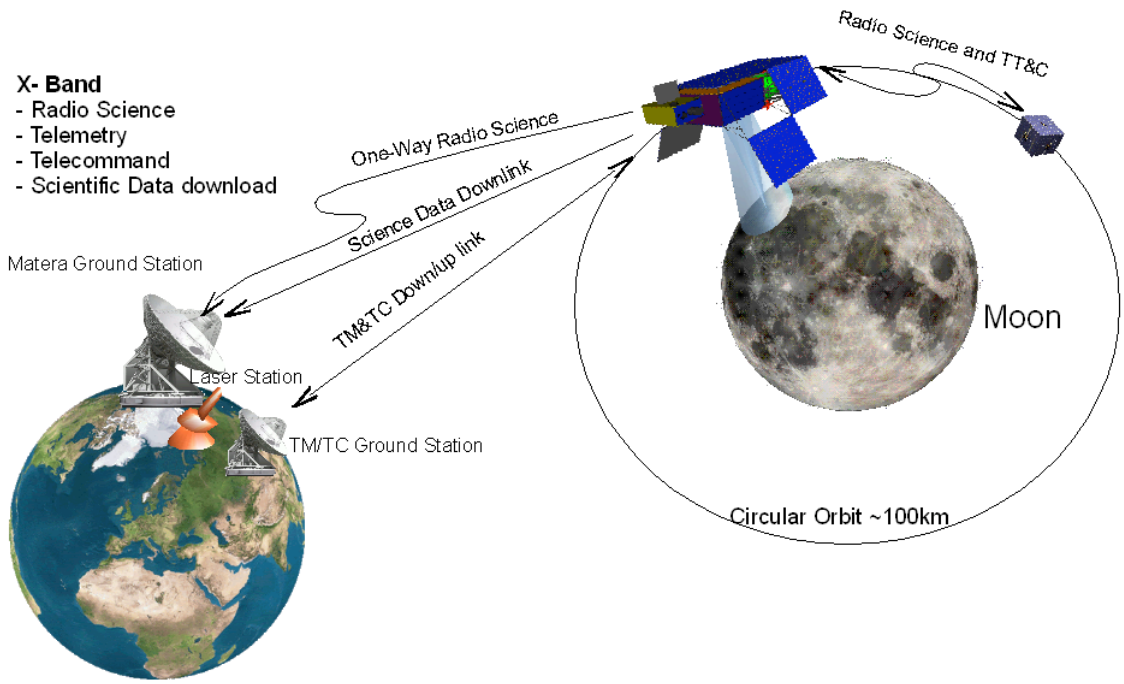

Figure 6.1—MAGIA Mission Concept

Two distinct mission phases are foreseen: the first devoted to lunar mapping and imaging and the second to the gravity experiment (this foresees the release of the subsatellite). Two slightly different nominal orbits have been selected for the two phases (Table 6.2).

Table 6.2—MAGIA Orbits by Mission Phase

Nominal orbital elements		
Phase	**Lunar imaging**	**Gravity experiment**
Semi-Major Axis	1838 km	1798 km
Eccentricity	0.00675	0.00675
Inclination	89.99	93.00
Argument of Perigee	270°	270°
Orbital period	2 hrs	2 hrs

Some scientific experiments can be performed during the Earth-Moon transfer. The mission timeline foresees 6 months for the first phase, and 1 month for the second one. The mission nominally lasts at least 9 months with a goal to extend up to 15 months.

The foreseen lunar orbiting mission profile is the following:

- 6 months of controlled operations in nominal mapping orbit; altitude must remain between 70 and 130 km
- Moving to gravimetric experiment nominal orbit
- At least 1 month of gravity field experiment

- Extended mission
- End of Life—lunar surface impact

The MAGIA mission is scheduled to occur in the 2012 to 2013 timeframe.

6.1.3 MAGIA Communication System

MAGIA telecommunications are concerned with

- Science data download
  - This function has to ensure, when in visibility, an appropriate link performance to download science data storied during eclipses at a rate of 4 Mbit/s. The use of a high-gain maneuverable antenna is necessary to allow this goal.
- Telemetry data download
  - Transmission of this data to Ground Segment needs a relatively low bit rate.
- Telemetry and Telecommand data upload
  - This link provides maneuvers, payload, and other commands to the spacecraft (S/C). This transmission can be operated at low bit rate.
- Subsatellite data download
  - This link allows for data transmission from subsatellite to main satellite. Due to the low quantity of data, information will be transmitted at a regular interval with a burst in the Radio Science signal.
- X-Band Radio Science
  - This link provides measurement of range rate. This is based on transmission of a carrier wave in X band; the receiver will measure Doppler frequency in order to evaluate range rate. This function can be operated in three different modes:
    - One way Space-Earth: S/C transmits a carrier wave signal to the Earth. Ground Station receives and determines Doppler frequency. S/C has to be provided of a Rubidium Atomic Frequency Standard (RAFS) oscillator to ensure frequency stability on transmission. This mode is the one chosen for the MAGIA satellite.
    - Two way: Ground Station transmit a carrier wave signal, this is received by S/C, frequency is down converted through multiplication and division and retransmitted to the Earth, enabling Round-trip Doppler to be measured. This mode is to be considered as an option.
    - One way Earth-Space: Ground station transmits a carrier wave signal to the S/C that receives it and measures Doppler frequency. This mode is also considered as an option.
  - Telecommunications system provides the required Signal to Noise Ratio (SNR) to perform a measurement with an accuracy of 0.1 mm/s.
- S-Band Radio Science

- This link provides measurement of reciprocal range rate between main and subsatellite. This measurement, supported by accelerometer data, is required to achieve the goal of a 1 mgal gravity field knowledge accuracy.

6.1.4 MAGIA Telecommunication Design: Link Requirements

The preliminary requirements for MAGIA include:

- Science data download link
  - 4 Mbit/s
  - High-gain steerable antenna
- Telemetry/Telecommand download link
  - Low gain antennas (LGAs)
  - Low bit rate
- Subsatellite data download link
  - Low data amount
  - Burst transmission
- X-Band Radio Science link
  - One way, space to Earth
  - Accuracy of 0.1 mm/s
- S-Band Radio Science link
  - Two ways
  - Accuracy of 0.01 mm/s

The MAGIA S/C will carry four antennas for the Earth-Space link: a maneuverable high gain antenna (HGA) for data downloading and Radio Science (in X band) and three low gain patch antennas for communications with Ground Stations (in X band) when HGA cannot be used. This scheme assures robustness to malfunctions and the contemporary transmission of payload data or TM (first at 4 Mbps, second at 1kbps) and carrier wave for Radio Science using programmable switch. Transmission frequencies are 8.4 GHz for Radio Science carrier wave and 8.5 GHz for data download. Available output power will be 20 W, 95% for Science Data download and 5% for Radio Science carrier wave.

The interface with the subsatellite has both a mechanical and an electrical component when the subsatellite is carried by MAGIA, and a RF one when the subsatellite has been ejected from MAGIA.

After the separation from MAGIA, the interface between the mother satellite and the subsatellite will consist of a two-way radiolink which, besides playing an essential function for the gravimetric experiment, handles subcarrier-generated telemetries and MAGIA-generated telecommands for both the subsatellite and ISA operation. The two-way RF link operates at S band.

Design parameters for the main satellite and subsatellite are shown in Table 6.3.

Table 6.3—MAGIA Telecommunication Design: Main Satellite

Main Satellite		
Link	**Parameters**	
Space-to-Earth Science data	S/C Antenna	HGA: Type: 30-cm-diameter planar slotted waveguide array Gain at boresight: 28.5 dB (decibel)
	TWTA	Transmitted power: 20 Watt (W)
	Transmitters	Frequencies: 8.45 GHz (data) and 8.5GHz (Radio Science CW) Bandwidth: maximum 3 MHz at 8.45 GHz Modulation: Quadrature Phase Shift Keying (QPSK)
	Ground Antenna	Matera Very Long Baseline Interferometer (VLBI) Gain at boresight: 65.3 dB
	Signal	Science Data signal + Continuous Wave (CW) for Radio Science Frequency Division Multiplexing (FDM) (power ratio about 12 dB) Data stream: Time Division Multiplexing (TDM) of Payload telemetries and science data at 4 Mbps Effective Isotropic Radiated Power (EIRP): 38.3 dBW (decibel Watts)
Space-to-Earth Telemetries	S/C Antenna	LGA: Type: patch antenna Gain at boresight: 6.0 dB
	TWTA	Transmitted power: 20 W
	Transmitters	Frequencies: 8.45 GHz (downlink data channel) and 8.5 GHz (Radio Science CW) Bandwidth: 2 kHz at 8.45 GHz Modulation: Pulse Code Modulation/Biphase Shift Keying/Phase Modulation (PCM/BPSK/PM) at 8.45 GHz
	Ground Antenna	Telemetry, Tracking and Control (TT&C) Station Gain at Boresight: 48.6 dB
	Signal	Telemetries Data stream: Telemetries at 0.1kbit/s EIRP: 11.8 dBW
Earth-to-Space Telecommand	Ground Station	TT&C Station Gain at boresight: 48.6 dB Transmitted power: 100 W
	Transmitter	Frequency: 7.145 GHz Bandwidth: 2 kHz Modulation: PCM/BPSK/PM at 8.45 GHz
	S/C Antenna	LGA: Type: patch antenna Gain at boresight: 6.0 dB
	Signal	Telecommand from Ground Segment EIRP: 68 dBW
Subsatellite		
Link	**Parameters**	
Mother-to-Son	Tx Antenna	Gain at boresight: 15 dB
	Transmitter	Frequency: 2.2 GHz Bandwidth: 0 kHz Modulation: Not Applicable (N/A)
	TWTA	Output power: 1W
	Rx Antenna	Gain at boresight: 6 dB
Son-to-Mother	Tx Antenna	Gain at boresight: 6 dB
	Transmitter	Frequency: Unknown, 21/22 of received signal frequency Bandwidth: ~0 kHz Modulation: BPSK
	TWTA	Output power: 0.5 W
	Rx Antenna	Gain at boresight: 15 dB
	Signal	CW at 21/22 of received signal frequency + BPSK burst for telemetry and payload data EIRP: -9.51dBW

6.1.5 MAGIA Ground Stations

About Ground Station configuration, two hypotheses have been considered:

- A large transmitting and receiving antenna
  - This choice, in order to satisfy a high data rate requirement for science data download, need a great diameter antenna (namely >10 m) with the capability to transmit and receive in X band. In order to achieve this goal, an upgrade of an existing VLBI station could be a solution providing all required functionality.
  - This solution contemplates a unique station for Tx/Rx of data and TC/TM.
- Two stations
  - Because of the criticality of high data rate scientific downlink, the choice of divide transmission and reception systems has been analyzed. The ground communication system is composed of
    - A large diameter receiving only antenna (namely a VLBI network station) for downloading of science data and payload telemetry and one-way (Space-Earth) Radio Science. Possibility of cooperation of other VLBI stations in order to perform a long interferometric baseline Precise Orbit Determination (POD).
    - A smaller (4-m) antenna for transmission of telecommand and reception of S/C telemetries.

The second option is the baseline configuration. The best candidate for data receiving is Matera VLBI Station. This location is strategic due to contemporary presence of a large antenna station (24 m), a Laser Station and a Microwave Amplification by Stimulated Emission of Radiation (MASER). Available power for telecommand transmission is 100 W at 7.15 GHz.

6.2 BNSC MoonLITE

At the time of writing (January 2009), MoonLITE is a proposed UK-led with U.S. participation small robotic mission (of less than 1 tonne at launch) to the Moon. The phase A study is due to start shortly. It comprises a polar orbiter and multiple instrumented penetrators would emplace a global network of three to four 13-kg (kilogram) science stations equipped with seismometers, heat sensors, and spectrometers and powered by primary batteries. Both orbiter and surface stations have a nominal 1-year life.

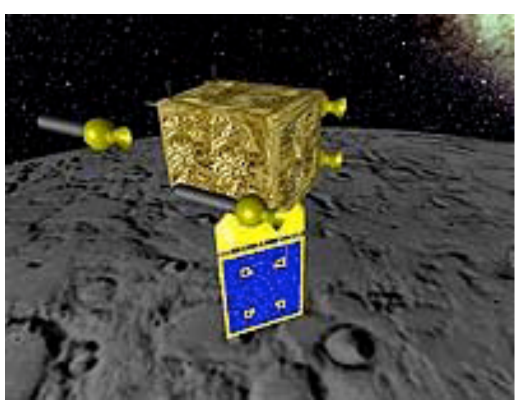

Figure 6.2—Artist's concept of the MoonLITE mission

6.2.1 Why develop the MoonLITE mission?

Given the successful launches of lunar missions such as the Small Mission for Advanced Research in Technology-1 (SMART-1), SELenological and ENgineering Explorer (SELENE), Chang'e and Chandrayaan-1 and the forthcoming LRO, MoonLITE offers a unique and timely opportunity to make important new and complementary robotic discoveries on the Moon in preparation for future human missions.

The U.S. and UK have enjoyed a long history of successful space cooperation. MoonLITE would build on this history and allow both partners the opportunity to take advantage of their relative strengths to build capacity and maximize national capabilities in a precursor mission to human activities on the lunar surface. In particular, the UK has expertise in the development and implementation of cost-effective small S/C missions, while the U.S. brings expertise in descent and landing systems, and these complementary capabilities provide an obvious central point for collaboration.

Beyond the immediate scientific return, MoonLITE would further advance the UK's world-class ability in small satellites; assist both partners in the development of capabilities needed for the exploration of the Moon, Mars, and beyond; and create a fertile environment for attracting and training skilled scientists and professionals.

While the UK is not yet in a position to commit to longer-term human aspects of lunar exploration, the two elements of the initial programme are nonetheless fully compatible with such a strategic involvement.

6.2.2 What benefits will MoonLITE deliver?

The ***science*** goals include investigating the following:

1. Size and physical state of lunar core
2. Deep structure of the lunar mantle
3. Thickness of the far-side lunar crust
4. Sources of natural Moonquakes

Exploration benefits arising from the science are to

1. Determine the natural seismicity of proposed lunar base locations, which will feed into engineering constraints on outpost designs.
2. Follow up on results from LRO and other orbiters by determining "in situ" the nature and composition of volatiles if present (with implications for both improved scientific knowledge and possible ISRU).

The direct contributions to the ***lunar architecture*** would be to

1. Test polar orbital telecoms (and possibly navigation) capabilities and
2. Validate the concept of a low-cost, recurring lunar telecom satellite design subsequently needed for the human lunar architecture.

Wider ***technological impacts*** would be to

1. Provide a platform for testing at the Moon certain technologies needed for exploration missions (especially descent and landing, as well as power and communications capabilities with ground assets) and
2. Demonstrate the use of highly instrumented penetrators for subsequent application to the scientific exploration of Mars, Europa, and other airless bodies in the solar system.

6.2.3 What Activities are Foreseen in the Science and Technology Programme?

MoonLITE will allow the first flight demonstration to validate key technologies needed for future human lunar exploration. By carrying out a joint programme and pooling collective knowledge and innovative thinking, MoonLITE would provide a key first step towards a visible and incremental buildup of capabilities needed to bring the U.S. Vision for Space Exploration into reality.

The Joint Project Team (JPT) will be a key body in coordinating and planning these activities by identifying areas of low technology readiness and developing appropriate technology roadmaps to ensure successful implementation of MoonLITE. Additionally, the JPT would further refine the science goals of the mission and oversee the process of instrument selection and tradeoffs to ensure successful implementation. Finally, the JPT would be tasked with supporting the U.S. and UK scientific communities through a series of workshops in coordination with existing meetings such as those held by the Lunar Exploration Analysis Group (LEAG).

6.3 CNES

CNES decided in 2008 to gain expertise on LGES design through a dedicated Phase 0 study called “Seismologic Lunar Network” (French: “Réseau Sismique Lune”). This study focuses primarily on the main functions of a lunar station, such as Control & Data Management, Power Handling, Communications, and Thermal Control of which designs depend on landing sites on the Moon.

Several scenarios based on this topic were produced as outputs with associated mass and power budgets. For programmatic and financial reasons, solar energy is considered as the unique power source of LGES, whereas Radioisotope Thermoelectric Generators are not considered.

Inputs considered for this mission are based on very wealthy scientific experiments with time-constraint measurements, which allow nodes synchronization inside the network. Scientific package is formed by

- Four seismologic chains with events synchronization to study lunar ground layers.
- A heater flow probe to perform lunar soil measurements up to 5 m in depth.
- Magnetic and electric sensors to realize on surface studies of lunar electromagnetic fields.
- Dose radiations measurements to ensure requirements compatibility for human exploration.
- A video camera to realize pictures of the lunar station environment.

An additional supply of 20% of power and data storage is made to allow the addition of other scientific instruments.

The scientific package with the other core subsystems should produce in average 30 Gbits of data per lunar cycle. These data need to be sent to the Earth through dedicated DTE or Data Relay Satellite links (allow Moon's far-side locations).

The core design is based on a modular approach for the main subsystems in order to

- Ensure a better insulation between scientific chains and core subsystems.
- Identify each function to allow alternative designs and specific optimizations on each, regarding to the mission.
- Allow international cooperation.

The architecture basis, which helps to fulfill mission objectives relays on the idea that the lunar station needs to be managed specifically according to lunar day and night periods. Through that way, it should be possible to minimize power consumption during lunar nights by performing autonomous functioning of scientific package and hibernating Common Data and Management System (CDMS) (a dedicated low-power chip can handle Fault Detection, Isolation, and Recovery (FDIR) and other critical tasks).

The LGES location selection on the Moon will be driven by many constraints, particularly, daytime and nighttime strategies, dating measurements, power regulation, and communications periods that require solar lighting to be functional.

Several tasks were conducted for the communication subsystem:

- Analyses were performed on the Direct-To-Earth and Data Relay Satellite approaches with distinction between far side, lunar disk, and equatorial locations.
- Several tradeoffs were realized on frequency bands and modulation and channel coding schemes to obtain different performance budgets.

Through the selected scenarios, it had been possible to identify and design communication components such as transceivers and antennas for the lunar station and the data relay satellite.

The study's conclusion states that solar energy designs are fully functional with quasi-developed technologies assuming that 24 W by lunar day and 6 W by lunar night are available. These power requirements ensure good quality scientific measurements due to a specific core station working on a lunar day and night basis.

The total mass budget of the station core can be evaluated at approximately 50 kg.

6.4 DLR

The German Space Agency Deutsches Zentrum für Luft- und Raumfahrt (DLR) continued its efforts for its Lunar Exploration Orbiter (LEO) mission. Phase A activities have been finished within 2008. The project will be continued as soon as a positive budgetary decision has been taken by the parliament and government.

6.5 JAXA

JAXA launched a lunar orbiter called Kaguya (also known as SELENE) in September 2007 and the S/C was successfully put into a lunar orbit in October of that year. It started observations with 14 onboard instruments and a couple of daughter satellites. The major objectives of this mission are to obtain scientific data concerning the lunar origin and evolution and to develop the technologies for the future lunar exploration such as lunar orbit insertion, Moon-pointing attitude control, observation instrumentation, or communications relay.

JAXA is developing plans for conducting Moon exploration projects programmatically and strategically. As the next step of Moon exploration, a lunar landing mission called SELENE-2 is being considered. It will land on the Moon surface and perform in situ scientific observation, environment investigation, and research for future lunar utilization including human activity. At the same time, it will demonstrate some key technologies for lunar and planetary exploration such as precise and safe landing, surface mobility, and night survival technologies.

The missions of SELENE-2 are defined as follows:

1. Development and demonstration of key technologies for future exploration
   - Safe and accurate landing technologies
   - Surface mobility: rover
   - Night survival technologies
2. In situ observation and investigation for science and future lunar utilization
   - Detailed and subsurface geological observation
   - Geophysics to know interior structure
   - Measure dust, radiation, and soil environment
   - Investigation of possible in situ resources
3. Contribution to international Moon exploration activity and meet public interest
   - Internationally coordinated missions
   - International payload (TBD)
   - Outreach or educational payload (TBD)

In the present design, SELENE-2 consists of a lander, a rover, and a communication relay orbiter. A twin lander configuration is also considered as an option. Candidates of landing sites are now under discussion. The lander carries laser altimeters, image sensors, landing radars for precise and safe landing. A laser scanning sensor for obstacle detection is also studied. The rover is designed to be able to travel in a wide area and observe featured terrain with scientific instruments and take selected samples back to the lander for detailed analysis. The lander has an automatic sample analysis package. For the development of the rover, studies of mobile gear, navigation sensors and algorithm, environmental testing, and system design are being conducted.

Candidates of scientific instruments are categorized as follows:

1. Detailed geological observation of particular area and surface or subsurface material investigation
   - Multiband panoramic camera, X-ray spectrometer, Gamma-ray spectrometer, infrared spectrometer, microscope with cutting and grinding mechanism, subsurface radar sounder, etc.
2. Geophysical observation
   - Broadband seismometer, heat-flow meter, magnetometer, polar zenith telescope for lunar motion measurement, and reflector for laser ranging
3. Astronomy from Moon surface
   - Low-frequency radio measurement

6.6 Korea

National Lunar Program

Based on national space program agenda/roadmap of Korea, the lunar orbiter mission is scheduled to be implemented by 2020 and lunar lander program by 2025. The Korea government will decide in 2009 if the lunar orbiter program schedule is to be accelerated to 2018 from 2020.

The mission payload has not been selected yet for lunar orbiter. The following are candidates:

- High-resolution stereo camera
- Mini-Synthetic Aperture Radar (Mini-SAR)
- LIght Detection And Ranging (LIDAR) Hyperspectral Imager
- Hyperspectral Imager

Other instruments are being considered for inclusion in the payload as well.

6.7 NASA

Although NASA's main role in the ILN will be that of a coordinator, it nevertheless will be a major participant as well. NASA has initiated multiple new lunar missions based on the President's Fiscal Year 2009 budget request including both orbiters and landers. These missions are robotic lunar science missions within the overall envelope of the U.S. Space Exploration Policy. One of these missions, a lunar lander network, the ILN, will address elements of the 2007 National Research Council (NRC) Report. The other NASA missions that are planned or under consideration are the Lunar Crater Observation and Sensing Satellite (LCROSS) and New Frontiers 3. The manned NASA Orion and Altair missions will start mid 2019 but are not described in this report.

The current schedule for implementation of these missions is given in Figure 6.3.

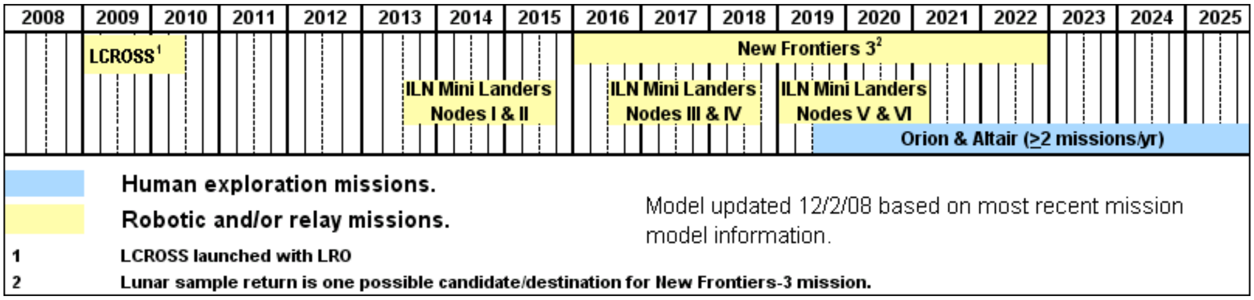

Figure 6.3—NASA Lunar Mission Set schedule

More detailed information on NASA's lunar missions is provided below.

6.7.1 NASA Planned Nodes for the ILN

The main objective of the U.S. nodes of the ILN is to understand the interior structure and composition of the Moon and include determining the size, composition, and state (solid/liquid) of the core of the Moon; characterizing the thermal state of the interior and elucidate the workings of the planetary heat engine; characterizing the chemical/physical stratification in the mantle, particularly the nature of the putative 500-km discontinuity and the composition of the lower mantle; and determining the thickness of the lunar crust (upper and lower) and characterizing its lateral variability on regional and global scales. ILN is a strategic mission that will address these goals to the extent possible within the limitations imposed by mass, cost, and duration of the proposed mission.

NASA chartered a U.S. ILN Science Definition Team (SDT) to provide analysis of potential high-valued science objectives that could be realized with a lunar network (LN) in order to provide an initial basis for discussions with the international community. Based on the recommendations of the U.S. ILN SDT, NASA has focused on the following types of instruments being considered for the ILN: seismometers, heat flow probes, electromagnetic probes, and laser ranging instrumentation. However, as the Core Instruments Working Group (CI WG) of the international ILN is still identifying a core instrument set, other available lightweight instrument types that could both provide complimentary data, make use of the unique capabilities of a LN, and that can be accommodated within the tight mass/power/cost constraints of the mission are still under consideration.

NASA's Anchor Nodes Project expects to emplace four nodes of the ILN, preferably with a single launch. The anchor node launch date will be dependent on mission costs in relation to available funding but will likely not occur before 2014 based on technical development schedules. The ILN mission requires long-lived instruments, which can be operated as a network for 6 years. Two additional nodes will be launched in the 2019 timeframe. All nodes will carry common core instrument payloads. The ILN mission requires long-lived instruments, which can be operated as a network for 6 years (the anchor nodes will necessarily have to last longer). It is anticipated that a very small amount of power will be available to enable continuous operation through the lunar night. Concept studies for the S/C are now under development at NASA's MSFC working with the Applied Physics Laboratory (APL) of The Johns Hopkins University. It is expected that the total available mass for all payload instruments will be approximately 15 kg, although the precise mass available for the payload will depend on the launch vehicle. The total available payload power will be approximately 15 W.

6.7.2 LCROSS

The LCROSS will be launched along with the LRO S/C. LCROSS is designed to search for water ice on the Moon's surface. The mission consists of a Shepherding Spacecraft (S-S/C) attached to the Centaur upper stage. The S-S/C will guide the Centaur after orbital insertion through two highly eccentric 40-day Earth orbits. The S-S/C then guides the Centaur into a trajectory, which will cause it to collide with a preselected permanently shadowed site on the Moon, chosen for its likelihood of containing water ice. The S-S/C will separate from the Centaur and perform a delay burn to follow 10 minutes behind. The Centaur will impact the lunar surface, throwing up a cloud of debris, possibly including water, hydrocarbons, and/or hydrated material. The S-S/C will take images and collect other data on the impact and cloud of ejecta before also striking the Moon. The S-S/C is built on an EELV Secondary Payload Adaptor (ESPA) ring with a dry mass of approximately 534 and 300 kg of hydrazine propellant. Power is supplied by a 420 W solar array charging a 40-A-h Li-Ion battery. Propulsion is through two 8-thruster pods and communications will be via two omnidirectional and two horn antennas operating at S band. The S-S/C will be equipped with two visible cameras, three infrared cameras, three spectrometers, and a photometer for observations.

Both uplink and downlink communications will be provided by the Deep Space Network (DSN) at S band. The LCROSS communication system can deliver 1.5 Mbps real-time data from the Moon to DSN 70-m dishes using one of the two medium gain horn antennas or can deliver 40 Kbps using one of the two omni antennas. The S-S/C will communicate using one of its omni antennas to a 34-m dish on Earth with telemetry rates up to 40 kbps. During final lunar approach and Centaur impact observation, the spacecraft roll attitude is controlled to provide +/-20° pointing for one of the two fixed-mounted medium-gain horn antennas (~12 dB gain) to provide a 1.5 Mbps downlink when using DSN 70-m dish assets. At least one of the three DSN sites has visibility to the spacecraft at all times. The White Sands Complex (WSC), which LRO plans to use as their primary ground station, has intermittent visibility (requiring comm. scheduling), approximately the same as the DSN Goldstone site. DSN 34-m stations, or WSC and other LRO backup sites around the world, could be used for routine TT&C.

6.7.3 New Frontiers 3

New Frontiers 3 is a preformulation mission, which has as its initial goal to return samples from the South Pole Aitkin Basin. It is currently scheduled for launch in 2016 and is expected to operate through 2022. It is expected to operate at S band, receiving its launch and early operations services from the Near Earth Network (NEN) and Space Network (SN). The DSN is expected to provide routine operational support.

6.7.4 Commercial C&N Opportunities

NASA conducted a study to investigate the potential for commercial lunar C&N in parallel with this ILN study. Conclusions of this study that are relevant to ILN are as follows:

- Based on an independent market assessment by Futron, a market for lunar communications sufficient to attract competitive commercial investment can be created.
- ILN is the primary government component of this nascent market in the 2013-2019 timeframe and provides a growth path to a larger market supporting robotic and human exploration in the 2020s.

- There are commercial service providers that are interested in serving this lunar communications market as evidenced both by Futron's market survey and the responses to a NASA Request for Information.
- It is in the interest of NASA to consider commercial partnerships to reduce lunar development and operations costs and to provide a means for transferring ownership to industry when the market matures and NASA has new goals to pursue.
- NASA must:
  - Provide leadership in creating the commercial services market;
  - Provide sufficient long term commitment to the use of commercial C&N services that commercial and international investment in lunar C&N can be raised;
  - Be willing to share control with its fellow stakeholders in this commercial communications services endeavor.
- The lunar communications market must be interoperable among national space agencies (i.e., using government spectrum and CCSDS and other international standards) but must also be open to use of commercial communications standards and spectrum to encourage growth of the commercial market.
- A Public/Private Partnership (PPP) is recommended as the implementation approach that enables investment by U.S. and international space agencies as well as domestic and foreign industry while providing means to mitigate risks to the stakeholders.

The study recommends that a second phase be conducted to: better quantify the potential revenue, costs, and risks; identify legal issues and responses; and to recommend how to set up the PPP. The study recommends that the ILN partners be invited to participate in this study.

The final study report titled "Commercial Lunar Communications and Navigation (C&N) Study: Final Report" is in publication and will be made available to the ILN partners. [9]

7.0 POTENTIAL INTERAGENCY CROSS SUPPORT FOR COMMUNICATIONS

The following ground and space physical assets have been identified within the ILN Comm WG membership that should be evaluated for its collaboration potential. It is recognized that other agencies, such as ESA, which are not participating in the ILN Comm WG at this time, may have assets that would be available to support ILN communication requirements as well. The evaluation of these, and any other further identified assets, will be carried out by the ILN Comm WG as one of its objectives for the year 2009.

7.1 Ground Facilities

This section provides preliminary identification of the ILN Comm WG member optical and RF ground assets, and their capabilities, that have potential for cross support of ILN communications.

7.1.1 ASI Ground Facilities

ASI national ground assets are:

- the “Luigi Broglio” Space Center (ASI-BSC).
- the Stratospheric Balloons Launch Base
- the Center for Space Geodesy “Giuseppe Colombo,” (ASI-CGS)
- the Sardinia Radio Telescope (SRT)

ASI considers as “national” ground assets the Telespazio “Piero Fanti” Fucino Space Center (FSC) located in Italy and owned/managed by Telespazio a Finmeccanica /Thales company. The FSC hosts 90 antennas on an extension of 370,000 square meters and it is located 130 km from Rome. The FSC is in operation since 1963 and is active in the areas of satellite orbit control, telecommunication, television, and multimedia services. The FSC hosts one of the two Galileo Control Centres. The control centers of ASI current mission are hosted at FSC.

ASI has moreover invested in developing ground assets through its membership in ESA.

ASI-CGS and SRT are the ground infrastructures concerned with possible cross support with ILN agencies and are treated in more details in the following chapters.

7.1.1.1 ASI “Luigi Broglio” Space Center

The ASI-BSC (Longitude: 40,19 degrees E, Latitude: 2,99 degrees S) is extended over an area about 3,5 hectares large on the coast of the Indian Ocean 32 km far from Malindi and may be reached through the littoral zone of Kenya. Because of its equatorial location on the Indian Ocean's coast, it is the ideal place for launch activities and satellite control from Earth. While the soil is a property of the Republic of Kenya, the management was entrusted to the University of Rome “La Sapienza” through the San Marco Project Research Centre (CRSPM) until 31 December 2003 and to ASI starting from 1 January 2004 in accordance with the intergovernmental agreements between Italy and Kenya currently in force. The presence of the Centre within the territory of Kenya, which goes back to 1966, is today ruled by an intergovernmental 15-year renewable agreement signed in 1995. This agreement involves the possibility to carry out launch activities, data acquisition from satellites, and remote sensing and training activities both in Kenya and in Italy.

The centre is made of two segments, the marine segment represented by the launch oceanic platform and the Earth segment represented by the data receipt centre. The last launch—Scout vector embarking the San Marco D/L satellite—was carried out on 25 March 1988. Since then platforms are not used and are generally submitted to the ordinary upkeep.

The Earth Segment involves:

- buildings made of masonry and wood used as accommodations and services
- a small seaport for docking the ships serving as a link with the platforms
- Three Earth Stations (antenna systems equipped with 10-m Sband, 10-m S/X/L band, and 6-m Xband)

Earth stations are used for:

- the in-orbit control of national and international programs
- control of launch vehicles (Arianespace, ULA)
- support to the first phases of satellites flight Launch and Early Orbit Phase (LEOP)
- acquisition of remote sensing data

The ASI-BSC Centre is permanently connected to Italy FSC via a redundant intersatellite (Intelsat) link at 2 Mbps.

7.1.1.2 ASI Stratospheric Balloons Launch Base

The base is located in the Sicily island region of Trapani-Milo and was opened in 1975. The launch base is located within an old airport 90 hectares large at the outskirts of Trapani, an ideal geographic location for trans-Mediterranean and transatlantic launches. It represents a world structure able to carry out the design, the launch, and the flight management of this specific technique, with a specialization in the systems of great mass and volume.

7.1.1.3 ASI Space Geodesy Center "Giuseppe Colombo"

The Centre for Space Geodesy (CGS) is dedicated to Professor Giuseppe ("Bepi") Colombo and is located in the south of Italy (district of Matera about 10 km east of the town). Opened in 1983 thanks to the joined effort of CNR's National Space Plan, Regione Basilicata and NASA, the CGS is a structure 5000 m^2 large where about 100 people work today.

The ASI-CGS is one of the most important space geodetic observatories in the international network, and has been since the beginning, part of the International Laser Ranging Service (ILRS), the International VLBI Service (IVS) and the International global navigation satellite system (GNSS) Service (IGS) both as an observing station and as a data analysis center.

Since 2004 the ASI-CGS is the Official Primary Combination Center of the ILRS.

The ASI-CGS hosts the following equipment:

- An advanced Satellite and Lunar Laser Ranging (SLR/LLR) Station, namely the Matera Laser Ranging Observatory (MLRO) with multi-wavelength millimetre-precision ranging capability, based on a 1.5-m aperture optical telescope;
- A VLBI observing station, based on a 20-m dish S/X radiotelescope and a MarkV-Very Long Baseline Array (VLBA) acquisition terminal;
- A fixed global positioning system (GPS) receiver;
- A nationwide fixed GPS network;
- A high-accuracy Absolute Gravimeter;
- Time and frequency system:
  - H-Maser frequency standard
  - Cs beam frequency standard
  - GPS synchronization

  - IRIG-B distribution
- Geodetic total stations;
- Advanced computing equipment and software;
- Advanced data analysis capability in SLR, VLBI, and GPS, producing single and multi-technique global geodetic solutions to estimate station coordinates, velocities, Earth rotation parameters, geopotential coefficients, non-gravitational perturbations, and precise orbits.

7.1.1.4 Sardinia Radio Telescope (SRT)

One of the most important purposes of the technology is the support to the radio and radar observations for the exploration of the solar system and the universe. Italy, recognizing the importance of these activities, during the last decade started the development of a national radiotelescope facility devoted to the observation of the natural radio sources. The geographical area for the radiotelescope was selected according to specific scientific and environmental constraints. After a site testing campaign, the site location was selected in the southern part of the Sardinia Island. Starting from the year 2010, the SRT shall be operational. SRT is based on a 64-m-diameter antenna, fully steerable, equipped with an Azimuth-Elevation (Az-El) tracking system.

SRT is sponsored by the

- Italian Space Agency
- Institute of Radioastronomy of the National Council of Research (CNR)
- Sardinian Autonomous Government, which cooperates through the Astronomical Observatory of Cagliari to the infrastructures set up, namely the foundation and technological supporting facilities

The SRT has been designed to perform

- Radioastronomy observations for the exploration of the solar systems and the universe (80%); and
- Interplanetary spacecraft mission Deep Space Communications (20%)

The Italian Space Agency (ASI) participated in the development of SRT in order to use this facility for DSN applications. As a consequence, the antenna shall be upgraded to decode telemetry signals transmitted by the interplanetary probes. It shall be also capable of transmitting commands to the probes. TT&C shall be possible in X and Ka bands. A Beam Waveguide (BWG) configuration shall be used to reach requirements in terms of G/T. The receiver chains shall be based on cryogenic amplifiers.

It is foreseen that SRT shall be ready to support DSN applications starting from the year 2012.

SRT shall be jointly operated by ASI and INAF (Istituto Nazionale di Astrofisica).

7.1.1.4.1 The SRT—Main Characteristics

The SRT Antenna has the following characteristics:

- 64-m reflector
- Wheel and track mount (mounted on an elevation over azimuth axis configuration)
- Active control of the reflecting surface
- Multiple feeds: prime focus, Gregorian, and BWG
- Spectral region 300 MHz to 100 GHz

The basic design will be for operation up to 22 GHz with the potential for upgrade for operation up to 100 GHz.

It is designed to operate in three focal regions:

- Primary Focus: 300 MHz to 1.4 GHZ—only receiving capability
- Secondary Focus (Gregorian): 2.2 to 100 GHz—only receiving capabilities
- Tertiary (BWG): 1.4 to 8.8 GHz—with transmitting capabilities

Its deep space frequencies capabilities include:

- X band—Rx and Tx simultaneously
- Ka band—Rx and Tx simultaneously

The transmitting power will be up to 1 KW at Ka band and up to 5 KW at X band (left-hand circular polarized (LHCP) and right-hand circular polarized (RHCP) selectable).

7.1.1.4.2 SRT—Project Schedule

The Antenna project construction is in progress:

- Antenna baseplate is in place.
- Antenna construction and assembling in progress. Completion is foreseen by the end of 2009.

The RF project to support deep space missions is in progress:

- RF preliminary system design has been completed.
- RF system project (B phase) starts at the end of January 2009, duration 5 months.
- RF system implementation starts second-half 2009, duration 3 years.

7.1.2 BNSC

The Rutherford Appleton Laboratory (RAL) ground station will be available for uplink and downlink as required. The 12-m antenna is currently configured for use on S band, with S and X band available on the 4.5-m antenna. The 12-m antenna can be configured for use on X band should the need arise. The systems are CCSDS compatible. The ground station is under automatic control when being used only for downlink, making it especially cost effective.

The QinetiQ satellite ground station at West Freugh, Scotland, boasts seven dishes up to 13 m in diameter to receive S-, L-, and X-band data links. The system is currently configured for S-band uplinks only, but upgradeable to X-band commanding. The coverage footprint for Earth observation extends from Polar Regions to North Africa and from Greenland across the whole of Europe. The facility is CCSDS compatible and was one of the first ground stations to demonstrate the use of CCSDS Space Link Extension (SLE).

UK funding agencies are considering whether there is a case for revitalizing the operation of the Goonhilly ground station. This could be particularly attractive for lunar operations as it offers access to a 32-m antenna, as well as to 13-m antennas. However, the status of Goonhilly is uncertain at present.

7.1.3 CNES

At this moment, CNES is unable to provide information on potential support concerning their ground tracking networks and space systems.

7.1.4 DLR

For optical downlinks from the Moon to the Earth, an optical telescope with a diameter of about 0.5 m is suitable for the ground segment. Several ground facilities meeting the lunar downlink requirements are available to DLR. Table 7.1 lists the available optical telescopes. Figure 7.1 is a photograph of DLR's Optical Ground Station—Oberpfaffenhofen (OGS-OP).

Table 7.1—Optical telescopes available to DLR.

Name	Location	Diameter	Operator	Comment
OGS-OP	Oberpfaffenhofen (Germany)	0.4 m	DLR	Satellite links already performed
ESA-OGS (Optical Ground Station)	*Tenerife (Spain)*	1 m	ESA	Satellite links already performed
TOGS	Transportable	0.6 to 0.9 m	DLR	Planned for 2010
Calar Alto telescopes	Calar Alto (Spain)	1.23 m, 2.2 m, and 3.5 m	Max Planck Institute & Instituto de Astrofísica de Andalucía	Astronomical telescopes

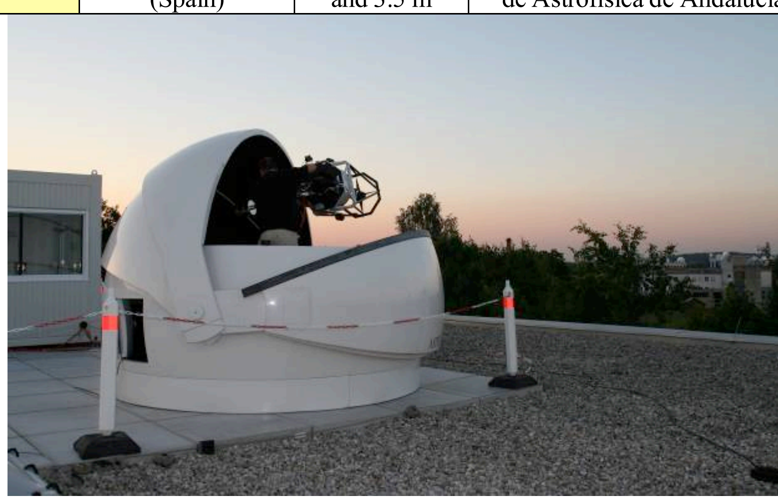

Figure 7.1—DLR's optical ground station (OGS-OP) on the roof of the institute; it consists of a 40-cm Cassegrain telescope with attached optical bench and a clamshell dome

Beside antenna systems dedicated for a specific mission, DLR operates antennas, which are also used for cross support (Table 7.2). The antennas located at Weilheim are operated by the GSOC (German Space Operation Center), all others by the DFD (German Remote Sensing Data Center). The locations of these stations are Neustrelitz (Germany) and O'Higgins (Antarctica).

Table 7.2—List of DLR stations

Antenna Dia (m)	Type	Location	S-band Uplink	EIRP (dBW)	S-band Downlink	Gain / G/T (dB/K)	X-band Uplink	EIRP (dBW)	X-band Downlink	Gain/ G/T (dB/K)
30 (S68)	D.S. (Deep Space)/ E.O. (Electro-Optical)	Weilheim, Germany	2110 - 2120	95	2200 - 2300	54/36	-	-	8400 - 8440	63/49
15 (S67)	E.O.	Weilheim, Germany	2025 - 2120	78	2200 - 2300	47.8/27.8	-	-	-	-
15 (S69)	E.O.	Weilheim, Germany	2025 - 2120	79	2200 - 2300	48.3/28.8	-	-	-	-
9 (S71)	E.O.	Weilheim, Germany	2025 - 2120	60	2200 - 2300	43.5/21.5	-	-	-	-
4.5 (S72)	GEO	Weilheim, Germany	-	-	2200 - 2300	37.5/16.8	-	-	-	-
7,3	E.O.	Neustrelitz, Germany	2025 - 2120	60	2200-2400	17,5	-	-	7600 - 8400	53/31
7,3	E.O.	Neustrelitz, Germany	-	-	2200-2400	17,5	-	-	8025-8400	53/31
7,3	E.O.	Neustrelitz, Germany	-	-	2200-2400	17,5	-	-	8025-8400	53/31
9	E.O.	O'Higgins, Antarctica	2025 - 2150	59	2200-2300	42/ 19-19,5	-	-	8025-8500	55,5/ 31,5-32

Different missions for non-DLR partners like the ESA missions Cluster, Integral, SMART, and the current Eutelsat HB10 are supported from Weilheim in the past.

For all of our stations a SLE provider interface is available to support return channel frames (RAF), return channel frames (RCF), and Command Link Transmission Unit (CLTU) functionality. For telemetry the support is available in both online and offline mode.

At the least, the 15-m antennas at Weilheim can be used for lunar missions. ESA's lunar mission SMART was supported in 2007 with these antennas. A support for the NASA LRO mission (24.4.2009 proposed launch date) is foreseen as part of the SSC network which supports NASA for this mission.

Beside that DLR is operating a Ku-band station at the Weilheim premises (Uplink: 13750 – 14500 MHz, EIRP 90 dBW, Downlink 10700 – 12750 MHz, Gain: 61 dB, G/T: 37 dB/K).

New antennas are under construction in

- Inuvik, Canada (11-m S/X-band)
- Weilheim (7.5-m Ka band)

7.1.5 JAXA

7.1.5.1 Usuda Deep Space Center (UDSC)

The JAXA Usuda Deep Space Center (UDSC) has a 64-m dish antenna that supports interplanetary S/C missions and radio astronomy observations for the exploration of the solar system and the universe. The antenna also supports selected Earth-orbiting missions. The center is located about 100 km northwest of Tokyo in the central part of Japan.

The antenna is capable of sending and receiving RF signals at S and X bands. The signal and data formats it supports are compatible with CCSDS standards. The station is connected with the Sagamihara Space Operations Center (SSOC) located in Sagamihara (about 30 km west of Tokyo) with a leased communications line. Telemetry reception and command radiation services can be provided for international partners in real-time using CCSDS SLE Services.

7.1.5.2 Uchinoura Space Center (USC)

The JAXA USC has 34-, 20-, and 10-m dish antennas. The 34-m antenna supports both interplanetary and Earth-orbiting missions, but the 20- and 10-m antennas only support Earth-orbiting missions. The center is located about 800 km southwest of Tokyo at the southern tip of Japan.

The 10-m antenna is capable of sending signals at S band and receiving signals at 400-MHz band and S band. The 20-m antenna is capable of sending signals at S band and receiving signals at S and X bands. The 34-m antenna is capable of sending and receiving signals at S and X bands. The signal and data formats they support are compatible with CCSDS standards. The stations are connected with the SSOC with a leased communications line. Telemetry reception and command radiation services can be provided for international partners in real time using CCSDS SLE Services.

7.1.6 Korea

7.1.6.1 Objective

For national lunar programs, a new antenna for TT&C and mission data is assumed to be developed and installed inside Korea by 2016. The main objective of the feasibility study of DSN was to decide the ground station link parameters like EIRP and G/T based on assumed onboard parameters.

For onboard parameters, the heritage space program like Korean Multi-Purpose Satellite (KOMPSAT) series was considered as baseline and the following were assumed:

- S band for Command (CMD) and Telemetry (TLM)
- X band for Instrument data: “Store & Forward”
- BER (bit error rate): 10^{-6} for CMD and 10^{-5} for TLM and Instrument Data

For instrument data downlink, the Ka-band frequency was not selected due to its heavy rain loss considering Korea’s annual rain rate, especially during the summer season.

7.1.6.2 Modulation and Data Rate

Based on heritage, the S-band uplink data rate is fixed to 2 kbps while the S-band downlink has two different rates; 2 kbps for real-time State of Health (SOH) TLM only, 512 kbps for real time and recorded stored SOH TLM.

For mission data downlink, the maximum 10 Mbps was selected considering onboard compression, onboard memory, and payload duty cycle.

S-band 512 kbps mode uses direct carrier phase modulation with a modulation index of 1.5 radian while 2 kbps up/down modes uses BPSK subcarrier modulation with a modulation index of 1.0 radian for carrier. These modes are shown in Table 7.3

Considering the long distance between Earth and lunar orbiter, the channel coding gain needed to be maximized. For this, convolution encoding and RS error correction code, which are CCSDS standard recommendations, were selected for maximum gain for telemetry. For S-band uplink command, CCSDS Bose-Chaudhuri-Hoequenghem (BCH) encoding was selected.

Table 7.3—Modulation Versus Communication Mode

Mode	Frequency	Modulation	Data Rate (bps)	Modulation Index (rad)	Remark
Uplink	2.0 to 2.1 GHz	PCM/BPSK/PM	2000	1.0	16 kHz subcarrier for CMD
Real-time SOH downlink	2.2 to 2.3 GHz	PCM/BPSK/PM	2048	1.0	1.024 MHz subcarrier for TLM
Real-time and stored SOH downlink	2.2 to 2.3 GHz	PM	512000	1.5	Direct carrier PM for TLM
Mission data downlink	8.0 to 8.5 GHz	NRZ-M/OQPSK	10000000	N/A	
NRZ-M: Non-Return-To-Zero Mark; OQPSK: Offset QPSK					

7.1.6.3 Orbiter Onboard Configuration

Considering the communication distance and orbiter's attitude during LEOP, cruise, and normal mission phase, several key orbiter onboard configuration characteristics were derived.

- Two different onboard S-band antennas
  - Omni-antenna for LEOP and safe-hold (contingency)
  - Medium gain antenna (50 cm diameter) for normal missions
- Medium gain antenna (50 cm diameter) for X band
  - Two-axis gimbal for onboard antenna operations
  - 15 W of onboard Tx power for S and X band
  - -36.5 dB/K of onboard Rx G/T for S band (Omni-antenna case)

The FSS (Frequency Selective Surface) type of sub-reflector was considered to be used for dual band with common main parabolic reflector.

7.1.6.4 Ground Station Parameter

Two candidate antennas of 18- and 26-m were selected and the following parameters were considered.

- Antenna Efficiency: 60%
- Tx Amp. Power: 2 kW (Klystron)
- Rx Low Noise Amplifier (LNA) Noise Temperature: 30K (NF: 0.4 dB)

Based on assumptions, the EIRP and G/T for two different antennas are summarized in Table 7.4.

Table 7.4—Ground Station Parameters

Antenna Diameter [m]	EIRP [dBW]	G/T [dB/K]	
		S-Band	X-Band
18	80.1	28.6	40.1
26	83.3	31.8	43.2

7.1.6.5 Link Analysis Summary

Uplink Analysis

S-band uplink margin calculation was done for two different onboard antenna types, omnidirectional and directional. This onboard antenna gain difference was directly reflected in onboard gain to temperature ratio (G/T).

Minimum 8.7 and 11.9 dB of net link margin above BER of 10^{-6} was shown for 18 m (80.1 dBW) and 26 m (83.3 dBW) cases, respectively.

Considering ample net link margins for directional antenna cases, the operational uplink EIRP can be reduced by 20 dB.

Table 7.5—Uplink Margin

Parameter	S-Band	
GS EIRP [dBW]	80.1/83.3	
Onboard Antenna Type	**Omni (0 dBi)**	**Directional (18.5 dBi)**
Onboard G/T [dB/K]	-36.5	-18
Data rate [kbps]	2	2
Received E_b/N_o [dB] (18 m/26 m)	19.5/22.7	38.0/41.2
Net Link Margin [dB] (18 m/26 m)	8.7/11.9	27.2/30.4

Downlink Analysis

For two different S-band downlink modes, the link margin of about 1.4 and 4.6 dB above BER value of 10^{-5} was revealed to be available for 18 m (28.6 dB/K) and 26 m (31.8 dB/K) cases, respectively (Table 7.6).

For X-band downlink, the minimum 3.5 and 6.7 dB of net link margin above BER of 10^{-5} was shown for 18 m (40.1 dB/K) and 26 m (43.2 dB/K) cases, respectively.

Table 7.6—Downlink Margin

Parameter	S-Band		X-Band
Onboard Antenna Type	**Omni (0 dBi)**	**Directional (19.2 dBi)**	**Directional (30.6 dBi)**
Onboard EIRP [dBW]	4.2	23.4	37.4
GS G/T [dB/K] (18 m/26 m)	28.6/31.8	28.6/31.8	40.1/43.2
Data rate [kbps]	2	512	10000
Received E_b/N_o [dB] (18 m/26 m)	3.6/6.8	3.7/6.9	5.9/9.1
Coding Gain [dB] (RS + Convolution)	7.4	7.4	7.4
Net Link Margin [dB] (18 m/26 m)	1.4/4.6	1.5/4.7	3.5/6.7

7.1.6.6 Tentative Schedule

The schedule for development of a DSN station for national lunar mission has not been finalized but the general schedule for the station follows:

- Feasibility study finalization: by mid 2009
- Installation site selection: by 2011
- Vendor selection: by 2012
- Installation and Test: by 2016
- Validation and Ops: 2017 (start date)

7.1.6.7 Summary

For Korea’s national lunar program, a DSN antenna (~26 m) is required by 2017. The antenna specification is not finalized yet. Based on the government’s decision in 2009, the time to implement the antenna will be finalized (accelerated or delayed).

7.1.7 NASA

7.1.7.1 Deep Space Network

The NASA Deep Space Network (DSN) is an international network of antennas that supports interplanetary S/C missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The network also supports selected Earth-orbiting missions.

Every U.S. deep space mission is designed to allow continuous radio communication with the S/C. Continuous 24-hour coverage for several S/C requires several Earth-based stations at locations that compensate for the Earth's daily rotation. The locations in Spain, Australia, and California are approximately 120 degrees apart in longitude, which enables continuous observation and suitable overlap for transferring the S/C radio link from one complex to the next.

The Australian complex is located 40 km (25 miles) southwest of Canberra near the Tidbinbilla Nature Reserve. The Spanish complex is located 60 km (37 miles) west of Madrid at Robledo de Chavela. The Goldstone complex is located on the U.S. Army's Fort Irwin Military Reservation, approximately 72 km (45 miles) northeast of the desert city of Barstow. Each complex is situated in semi-mountainous, bowl-shaped terrain to shield against RF interference.

Each complex consists of at least four deep space stations equipped with ultrasensitive receiving systems and large parabolic dish antennas. There are:

- One 34-m (111-ft) diameter high efficiency antenna
- One 34-m BWG antenna
  - Three at the Goldstone Complex and two in Madrid
- One 26-m (85-ft) antenna
- One 70-m (230-ft) antenna

All the stations are remotely operated from a centralized Signal Processing Center at each complex. The centers house the electronic subsystems that point and control the antennas, receive and process the telemetry data, transmit commands, and generate the S/C navigation data.

Once the data is processed at the complexes, it is transmitted to NASA Jet Propulsion Laboratory (JPL) for further processing and distribution to science teams over a modern ground communications network. Technical Information on the DSN can be found in the ***DSN Telecommunications Link Design Handbook.*** [10]

7.1.7.2 Near Earth Network

The NASA Near Earth Network (NEN) provides comprehensive communications services to space assets. The NEN provides telemetry, commanding, and tracking services for orbital missions and occasionally suborbital missions. The NEN provides services to a wide variety of mission customers, at various LEO, geosynchronous Earth orbits (GEOs), highly elliptical orbits, LaGrange orbits, and lunar and suborbital and launch trajectories, at multiple frequency bands through all phases of a mission's lifetime.

The NASA NEN consists of NASA ground stations located in Norway, Florida, Alaska, Antarctica, and Virginia. The NEN also includes support from the Network Integration Center (NIC) located at the NASA Goddard Space Flight Center (GSFC) and the NEN scheduling, White Sands 1 Ground Terminal (WS1) Ka-band and Very High Frequency (VHF) systems at the White Sands Complex, New Mexico.

Technical information on the individual NASA NEN ground stations can be found in the ***Ground Network User's Guide***. [11]

7.1.7.3 Space Network

The Space Network (SN) consists of two primary elements: the White Sands Complex (WSC) and a fleet of Tracking and Data Relay Satellites (TDRS) in geosynchronous orbit.

The WSC consists of three facilities. The two large facilities are known as the White Sands Ground Terminal (WSGT) and the Second TDRS Ground Terminal (STGT) and are located just outside Las Cruces, New Mexico (and are separated by approximately 6 miles). The third ground terminal in the SN is the Guam Remote Ground Terminal (GRGT). This facility, due to its location, allows the SN to offer complete global coverage for customers. Without this facility, there is a gap in coverage over the Indian Ocean. These facilities are staffed 24/7 to provide services to the SN user community in addition to being the control center for the TDRS constellation.

The fleet of S/C is situated in Earth orbit such that they can provide continual, global coverage. There are currently nine S/C in orbit; five of which are being used daily to support the low Earth customer community. Of these five S/C, two are located just off the coast of South America over the Atlantic Ocean, two are over the middle of the Pacific Ocean, and one is over the Indian Ocean. There is one satellite that is solely used to support National Science Foundation (NSF) operations at the South Pole and is not available for service to other customers. The other S/C are stored on-orbit as spares for the operational fleet.

The SN provides several services to its customers. They include telecommunications, tracking and clock calibration, testing, and analysis.

Telecommunications

This is the service that generally comes to mind when discussing the SN. This is the service that operates either via the Multiple Access (MA) or Single Access (SA) antenna systems on the TDRS. The MA system operates in the S-band frequency. The SA system operates in the S-, Ku-, or Ka-band frequencies (Ka band is only available on the TDRS H, I, J series of the S/C).

Telecommunication services are available as forward, return, or simultaneous services. Forward is the service that allows the customer control center to command their S/C. Return service is how customers receive their science data and the health and safety data for their S/C. Simultaneous service allows them to do both forward and return service at the same time.

These services are generally scheduled in advance by the customer control center. The schedule will be based on when their S/C is in view of a TDRS and when they need to communicate with their S/C.

A new capability to be given access to the MA system on demand (without prior scheduling) is being installed at the ground stations and will be operational in late 2003. In the initial implementation, this capability will be available for return service. As part of the upgrades budget, capability for demand access as a forward service will be added.

Tracking and Clock Calibration

This service provides the customer with the ability to understand their precise location in orbit using Doppler measurements. It also allows them to determine the accuracy of their onboard clock (and to make updates if necessary).

Testing

The SN provides two types of testing services: compatibility testing and end-to-end testing.

Compatibility testing is done to ensure that the communications package on the customer S/C is compatible with the communications system of the SN. This testing is performed while the customer S/C is in development.

End-to-end testing is performed at various points of the customer S/C lifetime. This testing can be performed using a ground-based simulator for the customer S/C. End-to-end testing performed prior to launch helps ensure the full operational capability of the customer system including operations and fault isolation procedures. End-to-end testing is also performed once the customer S/C has been launched to validate that changes made to either the customer systems or the SN will not cause problems in operations.

Analysis

Communications link analysis enables the customer to understand what the parameters of their communication system need to be in order to be able to communicate (or close the link) with the TDRS. Link analysis also examines the impact of locating the customer S/C antenna at various places on their S/C and what this would do to the communications link between them and the TDRS. This analysis is done during the design and development of the customer S/C communication system.

The ***Space Network User's Guide*** provides detailed information on Tracking and Data Relay Satellite System (TDRSS) and the associated ground stations supporting its operation. [12]

7.2 Space Assets

This section provides preliminary identification of the ILN Comm WG member optical and RF space assets that have potential for cross support of ILN communications.

7.2.1 BNSC MoonLITE Relay Function

The proposed MoonLITE mission will consist of a lunar orbiter and four penetrators. The orbiter will be in a polar lunar orbit and will provide a communications link between each penetrator and the Earth. The orbiter will also host a NASA-supplied Communications and Navigation experiment. The proposal is for there to be 1 year of penetrator operations with a (presumed) longer phase of C&N. The MoonLITE orbiter will have the capability of contributing to a network of orbiting communications systems that could form part of a LN.

7.2.2 DLR LEO

The German Space Agency DLR continued its efforts for its LEO mission. The LEO project concept was based on the conclusion that the Moon is of high interest for scientific and technological reasons. Germany therefore relies on Moon exploration activities, based on national and international or ESA cooperation.

The LEO Space Segment designed in a Phase A study consists out of one main satellite and two subsatellites. The subsatellites are carried to the Moon by the main satellite and are deployed by it into their nominal lunar orbit. LEO is scheduled to be launched in late 2012 on a Soyuz 2-1b launch vehicle with Fregat-M upper stage from Guiana Space Center/Centre Spatial Guyanais (GSC/CSG). The Fregat will insert the space segment into a direct trajectory to the Moon. The main satellite will use the onboard propulsion system to capture into lunar orbit. After main satellite commissioning, the space segment will first enter into the subsatellites nominal orbit of 50 km average altitude and 85° inclination. There the main satellite will deploy the subsatellites. The subsatellites will carry out a nominal mission of 4 years (goal). After completion of the nominal mission, the subsatellites may continue operations as part of an extended mission phase on the same orbit. After the subsatellites use all of the onboard fuel, their orbits will degrade and eventually impact the surface of the Moon. After the deployment of the subsatellites, the main satellite will enter its Nominal Orbit 1, which shares the basic characteristics of the subsatellites nominal orbit. After 3 years in its Nominal Orbit 1, the main satellite will carry out an inclination change to the polar Nominal Orbit 2 in which it will operate for 1 year.

LEO is featuring a set of unique scientific capabilities with respect to other planned missions including:

1. 100% global coverage of all remote sensing instruments with stereo resolutions of 1 m and spatial resolution of the spectral bands of <10 m.
2. Besides the Visible-Near Infrared (VIS-NIR) spectral range so far uncovered, wavelengths in the ultraviolet (0.2 to 0.4 µm) and mid-infrared (7 to 14 µm) will be globally mapped.
3. Subsurface detection of the regolith with a vertical resolution of about 2 m down to a few hundred meters (radar) and on mm-scale within the first 2 m (microwave-instrument) will investigate the regolith's structure.
4. Detailed measurements of the gravity field and magnetic field from a low orbit (<50 km) by two subsatellites and simultaneous Earth tracking, supported by measurements of radiation effects and two independent magnetometers will provide high precision and in addition will enable to geophysical investigate the far side.
5. The long mission duration of 4 years yields multiple high-resolution stereo coverage and thus monitoring of new impacts; this is supported by a flash detection camera searching directly for impact events and dust detection in the exosphere.

The LEO Space Segment consists of one main satellite and two identical subsatellites with a maximum total launch mass of 2150 kg.

Main Satellite

- Dimensions: 2000 × 1900 × 2000 mm^3
- Dry-mass ~1000 kg
- Propellant mass ~800 kg
- Onboard propulsion system for lunar orbit insertion and orbit/attitude control
- Solar array with 1 degree of freedom
- HGA with 2 degrees of freedom
- TT&C via X band
- High attitude control performance
- Payload data transmission via Ka band

2 Subsatellites

- Dimensions: 800 × 1400 × 680 mm
- Dry mass ~100 kg

- Propellant mass ~7 kg
- Cold-gas propulsion system for orbit and attitude control
- Minimal number of moving parts
- Stable centre of mass
- High magnetic cleanliness

Phase A activities have been finished within 2008. The project will be continued as soon as a positive budgetary decision has been taken by the parliament and government. It is already confirmed that exploration of the Moon remains a goal for German space policy, via ESA activities as well as for the National Programme in a medium timeframe.

7.2.3 JAXA SELENE-2

JAXA's SELENE-2 mission will have a lunar orbiter with capabilities of relaying data between landed elements on the Moon and ground stations. At this stage, the details of the relaying capabilities such as RF frequencies, data formats, and relaying modes (in real time and/or store and forward) that the orbiter supports are still under study and no definitive information is available.

7.2.4 NASA

7.2.4.1 Tracking and Data Relay Satellite System (TDRSS)

The SN space segment consists of a constellation of TDRSs. Up to six operational satellites in geosynchronous orbit relay forward and return data service and tracking signals to and from user platforms for data transfer and tracking. Two spare TDRSs are on orbit for replenishment purposes and will be pressed into service as older spacecraft attrition occurs, or as more ground terminals become available. The TDRSs are controlled, configured, and monitored through the TDRSS Operations Control Center (TOCC) located at White Sands, New Mexico.

This TDRS fleet is composed of the following:

- The basic TDRS program Flight 1 (or F1) through F6. (F2 was lost during the Challenger disaster.)
- The TDRS replacement program F7.
- The TDRS follow-on program, F8 through F10.

All first generation TDRSs, F1-F7, carry functionally identical payloads featuring two dual-band (S and Ku band) single access antennas and a phased array S-band antenna that applies ground-based beam forming for multiple access services.

The second-generation spacecraft, F8-F10, carry functionally identical payloads. The second-generation spacecraft maintain user service compatibility with the existing first-generation system but add the following new features:

- Enhancements that upgrade the performance of the Multiple Access (MA) system service performance.

- Addition of a new Ka-band Single Access (KaSA) service capability to be time-shared (selectable with ground command) with the Ku-band services.
- Block 2 spacecraft Ka-band services provide the same data rate capabilities as the existing Ku-band services; additionally, the spacecraft have the capability for higher bandwidth Ka-band services.
- Changes to the S- and Ku-band TT&C uplink and downlink frequency plans to permit independent control and user service from two collocated TDRS spacecraft. Collocated operations will enable either two second-generation spacecraft or one second-generation and one first-generation spacecraft to be operated in a single geostationary longitude by two WSC Space Ground Link Terminals (SGLT).

7.2.4.2 Lunar Network (LN)

NASA is conducting pre-formulation studies examining the need to establish a LN—a C&N network not to be confused with the ILN—to support NASA's Exploration Architecture and Constellation Program for Human Lunar Return. In 2006, the Lunar Architecture Team Phase 1 (LAT1) study included a Lunar Precursor Robotic Program (LPRP) that would have involved several lunar landers and required an early lunar relay satellite similar to the capability required for ILN. Subsequent studies have focused on the human exploration phase starting in 2020 requiring a more capable Lunar Relay Satellite (LRS).[13,13,14] It is recommended that the second phase of ILN studies include addressing a specific evolutionary path from relay support for ILN to LN support for human exploration.

8.0 TECHNOLOGY DEVELOPMENT

While the decision of which platform the ILN relay capability flies on has not been made, the requirements identified for ILN communications in this study can be met with existing technologies using largely off-the-shelf hardware. This offers a low cost, low risk approach to meeting the needs of the ILN that does not require any technology investment.

The human exploration era that starts in 2020 which may overlap the period of ILN operations offers an opportunity for synergy between programs as well as agencies that demand additional analysis in the next phase. The exploration community needs to be involved via the ISECG to consider the potential for using an ILN relay as a platform for flight demonstration of technologies needed in the 2020 timeframe for human exploration. Since lunar robotic science missions will continue to evolve in the same timeframe, any coupling of the ILN relay and the potential LN offers both opportunity and risk. The opportunity lies in sharing the development cost of the ILN relay with another partner—in this case the exploration programs within the same agencies that are ILN partners. The risk for ILN lies in the technical impact of adding additional payloads onto the spacecraft which may cause design conflicts that result in increased Size, Weight, And/or Power (SWAP). It also lies in the schedule risk introduced when parallel development efforts are integrated.

Technologies that are under development for the human exploration phase that would be candidates for flight demonstrations on an ILN relay (and in certain cases on ILN landers) include:

- Optical communications: NASA is investing in development of an optical communications capability for high bandwidth support to future deep space missions. The first flight demonstration is planned for a Lunar Laser Communications Demonstration (LLCD) to be flown on the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. Two other flight demonstrations are planned prior to establishing an operational laser communication trunk link from Earth to the Moon in late 2018 to support the initial deployment of the lunar outpost. ILN could become one of those demonstrations.
- Delay/Disruption Tolerant Networking (DTN): This technology adapts the Internet Protocol (IP) for the characteristics of space links including long delays and intermittent connectivity. CCSDS, the U.S. Defense Advanced Research Projects Agency (DARPA), and the Internet Research Task Force (IRTF) are collaborating on developing this technology which has military, civil, and commercial applications in terrestrial as well as space environments. Performing tests using an ILN relay with store-and-forward capability could be done with low risk to the ILN mission.
- Software Defined Radios (SDR): Radios that can be reprogrammed after launch offer the promise of being able to correct flaws that are not detected during system testing and upgrading performance on-orbit with improved software. Both ILN relays and landers may benefit from SDR technology in addition to the objective of producing space-qualified units and gaining operational experience with SDRs.
- Space-qualified high performance network router and modem: Similar to SDRs, the introduction of routed data using IP and/or DTN is expected to bring down the cost of space missions by enabling the use of commercial technologies. However, those terrestrial technologies still have to be modified for operation in the lunar environment and tested in space to raise their Technology Readiness Level (TRL). Introducing the use of network protocols into ILN would probably increase cost and risk on the early ILN nodes but would enable ILN to be readily integrated into the networked environment planned for the human exploration era.
- Multi-beam HGA: A multi-beam (or phased array) antenna is likely to be required for human exploration due to the number of simultaneous users on the surface including four Extravehicular Activity (EVA) astronauts, two rovers, deployable science packages ("suitcase science"), in situ resource utilization (ISRU) prototypes, Altair landers, and Orion crew vehicles. Addition of a multi-beam antenna on an ILN relay may allow relaxation of potential ILN site selection criteria since the relay may be able to talk to more than one ILN lander at a time. This could also reduce lander SWAP burden due to more frequent revisits which reduces the data storage requirement.

9.0 ACCOMPLISHMENTS

The ILN Communication WG achieved the following accomplishments in its first phase study:

1. Defined preliminary top-level operations scenarios that define where interoperability may be required between ILN participants when specific agreements for contributions are negotiated.
2. Got the preliminary operations scenarios incorporated into the SISG's Internetworking Roadmap.
3. Worked with the SISG and IOAG to the SISG's Internetworking Roadmap approved by the IOAG.
4. The international Inter-Operability Plenary #2 (IOP-2) adopted the recommendation to expand membership to include ILN participants. The IOP adopted the following resolution:
   - "Resolution 2: The IOP considers it as strongly beneficial for the IOAG to admit Membership of those Agencies having significant and relevant missions and assets respectively requiring and providing space C&N cross-support. The IOAG is encouraged to invite observers from other Agencies to participate in IOAG meetings as deemed necessary."
5. The IOP-2 agreed to adopt the Internetworking Roadmap that incorporates our proposed ILN communication scenarios. Relevant excerpts of the Joint Communiqué issued at the conclusion of the IOP-2 (10 December 2008) include the following:
   - "The IOP-2 meeting was attended by participants from ASI (Italy), CNES (France), CNSA (China), DLR (Germany), ESA (Europe), ISRO (India), JAXA (Japan), NASA (United States), and RFSA (Russia). Delegates thereto heard reports and recommendations from the IOAG, discussed its accomplishments to date, and considered the future course that the IOAG should take. A consensus emerged that expanding the current levels of international coordination and interoperability offers strong potential for enabling new missions, reducing costs, and increasing mission safety. Following these deliberations, and as the parent organization of the IOAG, the IOP formulated a set of IOP-2 Resolutions."
   - "Resolution 3: Furthermore, IOAG organizational processes should be adapted to collect and process in a timely manner all the space C&N requirements of other international space coordination groups (e.g., the International Space Exploration Coordination Group (ISECG), International Lunar Network (ILN), and international Mars exploration, inter alia), and to provide strategic guidance to the relevant standardization organizations (i.e., the Consultative Committee for Space Data Systems (CCSDS) and the Space Frequency Coordination Group (SFCG))."
   - "Resolution 4: The IOAG's *ground-based* Cross Support Service Catalog should be completed and agreed by all IOAG participants in order to establish a common basis across the Agencies for the consolidation of *ground-based* cross support by 2011. Agencies should agree to implement IOAG recommendations for missions, which

may benefit from cross support and/or international cooperation. It is an IOAG goal to have a plurality of the participating Agencies capable of providing *ground-based* cross support of an agreed common IOAG Service catalog by the end of calendar year 2015."

– "Resolution 6: The IOAG's Space Internetworking Strategy Group (SISG) should formalize a draft Solar System Internetwork (SSI) Operations Concept and candidate architectural definition in time for IOAG-13 and should prepare a mature architectural proposal for review and endorsement at the third Inter-Operability Plenary meeting (IOP-3). At that time, the IOAG is requested to present an enhanced service catalog for endorsement. The IOP Agencies should ensure representation from their programs and projects to work with SISG to identify potential missions, which may benefit from adoption of the SSI-related standards, leading to a gradual buildup of in-space and ground-based space internetworking infrastructure."

6. Communicated preliminary ILN spectrum needs to the SFCG. The SFCG has added ILN to their database of lunar missions and agrees to coordinate spectrum usage among ILN participants.
7. Presented ILN concepts of operation and interoperability concerns to the CCSDS Fall Conference in September 2008. CCSDS is willing to act on our recommendations for ILN communication needs that require new standards.

10.0 CONCLUSIONS

The ILN Communications WG concludes that:

1. The SDT recommendation for multiple far-side nodes drives the need for a communications relay. This is also required for access to areas that would otherwise be in a radio shadow, such as craters and polar regions.
2. The SDT recommends continuous data collection for one full 6-year lunar cycle. Multiple far-side ILN landers launched on different dates may increase the total time needed for communications relay operation beyond 6 years and up to 10 years. Communications relay coverage must be provided for this entire period. This can be met either with a single, long-lived relay satellite or two or more short-lived relay satellites.
3. The communications relay satellite should be placed into a lunar orbit and equipped with sufficient transmission and/or storage capacity that the relay design does not impose any additional requirements on the ILN landers for location, storage, data rate, or transmit/receive power.
4. The far-side, polar, and shadowed crater landers drive the design of key performance requirements for both the lander and relay C&N subsystems. Key parameters include data rates, pass duration, mass storage, lander revisit rates based on the relay orbit, position determination, and landing accuracy.
5. To minimize the cost of both ILN landers and relay satellite(s), all ILN landers should be required to use (a) the same spectrum; (b) one (or at most two) common set of communications standards for coding, modulation, link protocol, and forward and return data services; and (c) storage capacity based on the maximum revisit time and daily data volume.
6. ILN landers that will be targeted for near-side landing sites will still benefit from using the communications relay satellite (a) to minimize the SWAP requirements for their Command and Data Handling (C&DH) and Communications subsystems and (b) to enable a common design to be used for all landers.
7. The communications relay satellite design should be designed to accommodate the link budget of the lowest power lander among the ILN participants. For example, a penetrator may have no gain for reception or transmission.
8. No need for LRRs on lunar far-side landers.
9. Several agencies are studying orbiters as planned or potential relays associated with lunar landers that should be considered as candidates for the ILN communications relay. Agencies that would like to study this option include BNSC.
10. While cost estimates were not performed as part of this study phase, the lowest cost option is likely to be collaboration between two agencies providing the orbiter and the communications payload.
11. The need date for the relay is driven by the launch date of the far-side landers.

12. Far-side landers do not need LRRs as part of the Core Instrument set. Consequently, the communications relay does not require a laser ranging capability and does not offer an opportunity for technology demonstration of optical communications.
13. ILN nodes predicted to be launched in the 2016 to 2017 timeframe with a 6-year lifetime will overlap early Human Exploration starting in 2020 imposing the requirement for the communications architecture to evolve gracefully from the robotic (ILN) era to the joint robotic and human era presenting an opportunity for the ILN communications relay to test out communications, networking, and navigation technologies that advance TRLs and mitigate technology risks associated with the human exploration architecture.
14. There does not appear to be significant spectrum issues associated with an ILN communications relay that follows the recommendations of the SFCG's Lunar Mars Spectrum Coordination Group.
15. Candidate communications scenarios for ILN missions have been incorporated into the "Recommendations on a Strategy for Space Internetworking," dated 15 November 2008 (Internetworking Roadmap), adopted by the members of the IOP and IOAG and the Roadmap based on the development of interoperable standards among the IOAG members providing considerable flexibility in developing collaboration options among the ILN partners.

11.0 RECOMMENDATIONS

Recommendations for the ILN Communication WG in the next phase of investigation are:

1. Participate directly in the SISG's development of an implementation plan based on the "Recommendations on a Strategy for Space Internetworking";
2. Conduct a BNSC-NASA bilateral study of the potential for NASA to provide a communications payload for ILN use on BNSC's proposed MoonLITE mission;
3. Work with the SFCG's LMSCG to establish specific spectrum recommendations for ILN;
4. Conduct a study with NASA's Exploration Systems Mission Directorate on options for evolution of the lunar communications from robotic ILN support to robotic and human support;
5. The utility of an ILN relay should be discussed with the International Space Exploration Coordination Group (ISECG) and those agencies pursuing other lunar missions in addition to ILN;
6. On receipt of the report by the Core Instrument WG, conduct a pre-formulation study of options to meet the ILN communication needs based on emerging science requirements and potential ILN partner contributions;
7. Conduct a study to identify common communications practices for ILN missions;
8. Prepare preliminary communication requirements including alternate or prioritized sets of requirements if needed to address options identified by the Core Instrument WG;
9. Study the existing and planned CCSDS standards and recommend any changes needed to support ILN including: a) assessing the ability of ILN members to implement the minimum set of standards needed to conduct ILN missions; b) identifying impact to ILN member facilities to implement the minimum set of standards; and c) assessing technical and schedule changes to CCSDS plans if any to meet ILN needs;
10. Based on NASA's Commercial Lunar Communications and Navigation Study report and assess the potential for ILN use of a commercial communications service provider. ILN members should participate in the next phase of NASA's Commercial Lunar C&N Study;
11. Continue to identify ILN member ground and space assets that could be used to support ILN missions and work with the IOAG to update their data on these capabilities;
12. Support the ILN members in implementing the IOP resolutions that affect (or are affected by) ILN;
13. Study the impacts of landing sites on the far side or in permanently shadowed or polar craters on relay orbits, pass duration, and revisit frequency and the corresponding impacts on the design of landers and the surface-orbiter communications links.
14. Timing requirements were not specifically addressed during this study cycle by this WG and should be studied to determine those requirements, if any.
15. An implementation of common test beds to test cross support interoperability would be useful and should be investigated.

16. Coordination with the Site Selection WG should be done to refine communication requirements and the resulting cost and capabilities of the lunar relay.
17. Optical high speed downlinks should be considered as an important enabling technology for lunar and other exploration missions and international cooperation and standardization in this field should be fostered.

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APPENDIX A—INTERNATIONAL LUNAR NETWORK (ILN) COMMUNICATIONS WORKING GROUP MEMBERSHIP

Agency	Member	Email	Position
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KARI	Sang-Il Ahn	siahn@kari.re.kr	Head, Ground System Development Department
ETRI	Dr. Byoung-Sun Lee	lbs@etri.re.kr	Principal Researcher, Satellite Control and Navigation Research Team
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NASA	Brian Morse	Brian.Morse@jhuapl.edu	ILN Anchor Node Project Program Manager, Lunar Exploration, Johns Hopkins University Applied Physics Laboratory
NASA	Cheryl Reed	Cheryl.Reed@jhuapl.edu	Alternate for ILN Anchor Node Project

APPENDIX B—INTERNATIONAL LUNAR NETWORK COMMUNICATIONS WORKING GROUP (ILN Comm WG)

TERMS OF REFERENCE (TOR)

Background

1. The International Lunar Network (ILN) will establish a robotic network on the surface of the Moon to provide significant scientific value to the exploration of the Moon. The network will be gradually established by placing on the surface of the Moon, potentially including its far side and/or polar regions, robotic landers or other vehicles equipped with instruments from a to-be-agreed-upon set of scientifically equivalent core instrumentation to carry out specific measurements. This core set of instrumentation will allow intercomparison of measurements from instruments from different countries. Space agencies taking part in the ILN concept would, at their discretion, be free to include their own instruments or capabilities beyond those in the core suite.
2. Participation in the ILN will come through the contribution of landers, orbiters, instrumentation, or other significant infrastructure contributions, including communications capabilities. Additional participants are welcome to join the ILN concept when they are programmatically and financially prepared to do so.
3. Interoperable spectrum and communications standards will be coordinated through existing organizations. Membership in these organizations will be extended as needed to ILN participants who may not be current members.
4. The terms of reference for the working groups will be drafted and agreed upon by all ILN concept participants and will focus on fully understanding the opportunities and advantages of the potential cooperation.
5. The Communications WG will provide feedback to the signatories of the ILN Statement of Intent by the end of 2008.
6. All activities to be initiated as a result of the technical working group discussions will be documented by appropriate international agreements.
7. Communications in the context of this WG refers to the transmission of data as well as tracking, ranging, timing, and collateral capabilities created by exploiting the properties of electromagnetic radiation.

Objectives

The objectives of the ILN Communications Working Group for 2008 are

1. Support the ILN member discussions concerning member agencies' contributions in terms of communications capabilities and their operational period
2. Accept science and instrument requirements from the Core Instrument WG
3. Determine ILN communications requirements derived from individual member inputs and the Core Instrument WG's requirements

4. Promote the expansion of the SFCG, SISG, IOAG, CCSDS, and IOP to include all members of the ILN who desire membership
5. Work with the SFCG to ensure that ILN spectrum needs are incorporated into SFCG's recommendations
6. Work with the SISG to ensure that the strategic plan supporting international interoperability recommended by SISG to the IOAG reflects the protocols and standards desired to support the ILN
7. Work with the IOAG to ensure that the strategic plan supporting international interoperability recommended by the SISG is adopted and recommended to the IOP
8. Work with the CCSDS to ensure that ILN standards and protocol needs are incorporated into CCSDS recommended standards
9. Work with the IOP to ensure that the strategic plan supporting international interoperability recommended by the IOAG is adopted
10. Provide initial communications recommendations to the ILN Steering Group by December 2008

Procedures

1. The Communications WG will hold an initial meeting in conjunction with the signing of the ILN Statement Of Intent.
2. The Communications WG will hold periodic teleconferences as agreed by the members.
3. Working materials of the Communications WG will be posted on an ILN web site that will be accessible to all ILN members.
4. The Communications WG will report progress at ILN Steering Group meetings and telecons.

Structure/Responsibilities

1. The Communications WG will be co-chaired by NASA and JAXA.
2. Membership in the Communications WG is open to all agencies that are signatories to the ILN Statement of Intent.

Membership

(See Appendix A of this report.)

APPENDIX C—INTERNATIONAL LUNAR NETWORK COMMUNICATIONS WORKING GROUP (ILN Comm WG)

DRAFT TERMS OF REFERENCE (TOR)-2009

Background

1. The International Lunar Network (ILN) will establish a robotic network on the surface of the Moon to provide significant scientific value to the exploration of the Moon. The network will be gradually established by placing on the surface of the Moon, potentially including its far side and/or polar regions, robotic landers or other vehicles equipped with instruments from a to-be-agreed-upon set of scientifically equivalent core instrumentation to carry out specific measurements. This core set of instrumentation will allow inter-comparison of measurements from instruments from different countries. Space agencies taking part in the ILN concept would, at their discretion, be free to include their own instruments or capabilities beyond those in the core suite.
2. Participation in the ILN will come through the contribution of landers, orbiters, instrumentation, or other significant infrastructure contributions, including communications capabilities. Additional participants are welcome to join the ILN concept when they are programmatically and financially prepared to do so.
3. Interoperable spectrum and communications standards will be coordinated through existing organizations. Membership in these organizations will be extended as needed to ILN participants who may not be current members.
4. The terms of reference for the working groups will be drafted and agreed upon by all ILN concept participants and will focus on fully understanding the opportunities and advantages of the potential cooperation.
5. The Communications WG will provide a report to the signatories of the ILN SOI by the end of each calendar year or as necessary when requested to by the ILN Steering Committee.
6. All activities to be initiated as a result of the technical working group discussions will be documented by appropriate international agreements.
7. Communications in the context of this WG refers to the transmission of data as well as tracking, ranging, timing, and collateral capabilities created by exploiting the properties of electromagnetic radiation.

Objectives

The objectives of the ILN CommWG for 2009 are to:

1. Support the ILN member discussions concerning member agencies' contributions in terms of communications capabilities and their operational period;
   - Review ILN partners communication assets for their collaboration potential.
2. Promote the expansion of the SFCG, SISG, IOAG, CCSDS, and IOP to include all members of the ILN who desire membership.

3. Identify and recommend common communications practices for ILN missions including both an elaboration of existing common practices and proposals for new ones;
   - Investigate the possible implementation of common test beds for use by ILN partners to test cross support interoperability.
4. On receipt of the report by the Core Instrument WG, conduct a pre-formulation study of options to meet the ILN communication needs based on emerging science requirements and potential ILN partner contributions;
   - Prepare preliminary communication requirements including alternate or prioritized sets of requirements, if needed, to address options identified by the Core Instrument WG;
   - Review and modify as necessary, ILN communications requirements derived from individual member inputs and the Core Instrument WG's requirements.
5. Based on NASA's Commercial Lunar Communications and Navigation Study report, assess ILN partnership use of commercially provided lunar communication and navigation capabilities.
6. Coordinate with the ILN Core Instrument, Technology and Site Selection WGs to ensure that ILN requirements are fully addressed throughout each ILN WG.
7. Study the existing and planned CCSDS standards and recommend any changes needed to support ILN including: a) assessing the ability of ILN members to implement the minimum set of standards needed to conduct ILN missions; b) identifying impact to ILN member facilities to implement the minimum set of standards; and c) assessing technical and schedule changes to CCSDS plans if any to meet ILN needs;
   - Work with the CCSDS to ensure that ILN standards and protocol needs are incorporated into CCSDS recommended standards.
8. Coordinate with the SFCG to ensure that ILN spectrum needs are addressed.
9. Investigate possible ESA and Russian Federal Space Agency (RFSA) participation in the ILN thorough their provision of ground and space cross support to ILN operations.
10. Work with the SISG to ensure that the strategic plan supporting international interoperability recommended by SISG to the IOAG reflects the protocols and standards desired to support the ILN.
    - Participate directly in the SISG's development of an implementation plan based on the "Recommendations on a Strategy for Space Internetworking."
11. Determine the issues and options for evolution of the lunar communications from robotic ILN support to robotic and human support;
12. Determine ILN timing requirements, if any;
13. Through discussion with the International Space Exploration Coordination Group (ISECG) and those agencies pursuing other lunar missions in addition to ILN, determine the utility of an ILN to all involved parties;
14. Review previous recommendations made by the Comm WG to the ILN Steering Committee and revise as necessary;

15. Investigate the implementation of optical high speed downlinks for lunar and other exploration missions and the necessary international cooperation and standardization necessary to accomplish this;
16. Coordinate with the Site Selection WG (when formed) to determine communication requirements and the resulting capabilities of the lunar relay as well as site selection criteria driven by communication considerations.

Procedures

1. The Communications WG will hold periodic teleconferences as agreed by the members.
2. Working materials of the Communications WG will be posted on an ILN Web site that will be accessible to all ILN members.
3. The Communications WG will report progress at ILN Steering Group meetings and telecons.

Structure/Responsibilities

1. The Communications WG will be co-chaired by NASA and JAXA.
2. Membership in the Communications WG is open to all agencies that are signatories to the ILN SOI.

Membership

(See Appendix A of this report.)

APPENDIX D—GLOSSARY

ΔV	Delta velocity or change in velocity
ADM	Attitude Data Messages
AOS	Advance Orbiting Systems
APL	Applied Physics Laboratory
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
BCH	Bose-Chaudhuri-Hoequenghem
BER	Bit Error Rate
BNSC	British National Space Centre
BPSK	Biphase Shift Keying
BSC	Broglio Space Center
BWG	Beam Waveguide
C&DH	Command and Data Handling
C&N	Communications and Navigation
CAM_SIR	Infrared spectrometer and context camera for MAGIA
CCR	Cube corner retro-reflector
CCSDS	Consultative Committee for Space Data Systems
CDMS	Common Data and Management System
CGS	Center for Space Geodesy
CI WG	Core Instruments Working Group
CLTU	Command Link Transmission Unit
CMD	Command
CNES	Centre National d'Etudes Spatiales
CNR	National Council of Research
CRPSM	Centro di Ricerca Progetto San Marco
Cs	Cesium
CSA	Canadian Space Agency
CW	Continuous Wave
DARPA	Defense Advanced Research Projects Agency
dB	Decibel
dBW	Decibel (Watts)

DFE	Direct-From-Earth
DLR	Deutsches Zentrum für Luft- und Raumfahrt
D.S.	Deep Space
DSN	Deep Space Network
DTE	Direct-To-Earth
DTN	Delay Tolerant Network
E_b/N_0	Energy per bit to Noise power spectral density ratio
EESS	Earth Exploration-Satellite Service
EIRP	Effective Isotropic Radiated Power
EM	Electromagnetic
EO	Electro-optical
EPO	Education and Public Outreach
ESA	European Space Agency
ESA-OGS	ESA Optical Ground Station
ESPA	EELV Secondary Payload Adaptor
ETRI	Electronics & Telecommunications Research Institute (Korea)
EVA	Extravehicular Activity
FDIR	Fault Detection, Isolation, and Recovery
FDM	Frequency Division Multiplexing
FSC	Fucino Space Center
FSS	Frequency Selective Surface
GEO	Geosynchronous Earth Orbit
GES	Global Exploration Strategy
GHz	Gigahertz
GN	Ground Network
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRGT	Guam Remote Ground Terminal
GSFC	NASA Goddard Space Flight Center

GSC/CSG	Guiana Space Center / Centre Spatial Guyanais
G/T	Gain to Temperature Ratio
HGA	High Gain Antenna
Hz	Hertz (cycles/second)
IBTF	Integrated Bangalore TTC Facilities
ICSSC	International Communications Satellite Systems Conference
IEEE	Institute of Electrical and Electronic Engineers
IGS	International GNSS Service
ILEWG	Lunar Exploration Working Group
ILN	International Lunar Network
ILN Comm WG	ILN Communications Working Group
ILRS	International Laser Ranging Service
INAF	Istituto Nazionale di Astrofisica
IOAG	Interagency Operations Advisory Group
IOP	Interoperability Plenary
IP	Internet Protocol
IRTF	Internet Research Task Force
ISA	Accelerometer on MAGIA
ISAS	Institute of Space and Astronautical Science
ISECG	International Space Exploration Coordination Group
ISL	Intersatellite Service crosslLink
ISRO	Indian Space Research Organization
ISRU	In Situ Resource Utilization
ISTRAC	ISRO Telemetry, Tracking and Command Network
ITU	International Telecommunication Union
IVS	International VLBI Service
JAXA	Japan Aerospace Exploration Agency
JPL	NASA Jet Propulsion Laboratory
JPT	Joint Project Team
K	Degrees Kelvin
KARI	Korea Aerospace Research Institute

KaSA	Ka-Band Single Access
kbps	kilo bits per second
kg	kilogram
KOMPSAT	Korean Multi-Purpose Satellite
KREEP	Potassium-Rare Earth Element-Phosphorus
LADEE	Lunar Atmosphere and Dust Environment Explorer
LAT1	Lunar Architecture Team Phase 1
LCROSS	Lunar Crater Observation and Sensing Satellite
LEAG	Lunar Exploration Analysis Group
LEO	Lunar Exploration Orbiter
LEOP	Launch and Early Orbit Phase
LGA	Low gain antenna
LGES	Lunar Geophysical and Environmental Station
LGRS	Lunar Gravity Ranging System
LHCP	Left-Hand Circular Polarized
LIDAR	Light Detection And Ranging
LLCD	Lunar Laser Communications Demonstration
LLO	Low Lunar Orbit
LLR	Lunar Laser Ranging
LMSCG	Lunar and Martian Spectrum Coordination Group
LN	Lunar Network
LNA	Low Noise Amplifier
LOLA	Lunar Orbiter Laser Altimeter
LPRP	Lunar Precursor Robotic Program
LPSC	Lunar and Planetary Science Conference
LR	Laser Ranging
LRO	Lunar Reconnaissance Orbiter
LRR	Laser Retroreflector
LRS	Lunar Relay Satellite
MA	Multiple Access
MAGIA	Missione Altimetrica Gravimetrica geochImica lunAre

MASER	Microwave Amplification by Stimulated Emission of Radiation
MB	Megabytes
Mbits	Megabits
Mbps	Megabits per second
mGal	milli Galileo (= 0.01 m/s^2)
MHz	Mega Hertz
MLRO	Matera Laser Ranging Observatory
mm	millimeter
MoonLITE	Moon Lightweight Interior and Telecoms Experiment
MSFC	Marshall Space Flight Center
N/A	Not applicable
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NIC	Network Integration Center
NRC	National Research Council
NRZ-M	Non-Return-To-Zero Mark
NSF	National Science Foundation
ODM	Orbit Data Messages
OGS-OP	Optical Ground Station—Oberpfaffenhofen
OQPSK	Offset Quadrature Phase Shift Keying
PKT	Procellarum KREEP Terrane, an oval centered at ~ 20°N, 30°W, and comprising ~15% of the lunar surface
PN	Pseudo-Noise
PNT	Position, Navigation, and Timing
POD	Precise Orbit Determination
PPP	Peer to Peer Protocol, Public/Private Partnership
QPSK	Quadrature Phase Shift Keying
rad	radian
RADIO	Energetic particle spectrometer on MAGIA
RAF	Return All Frames
RAFS	Rubidium Atomic Frequency Standard

RAL	Rutherford Appleton Laboratory
RASCAL	Radar altimeter, radiometer and scatterometer
RCF	Return Channel Frames
RF	Radiofrequency
RFSA	Russian Federal Space Agency
RHCP	Right-Hand Circular Polarized
RSS	Root-Sum-Square
Rx	Receive
SA	Single Access
S/C	Spacecraft
SCaN	Space Communications and Navigation
SCEM	Scientific Context for Exploration of the Moon
SDR	Software Defined Radios
SDT	Science Definition Team
SELENE	SELenological and ENgineering Explorer
SFCG	Space Frequency Coordination Group
SGLT	Space Ground Link Terminal
SISG	Space Internetworking Strategy Group
SLE	Space Link Extension
SLR	Satellite Laser Ranging
SMART	Small Mission for Advanced Research in Technology
SN	Space Network
SNR	Signal to Noise Ratio
SNUG	Space Network User's Guide
SOH	State of Health
SOI	Statement of Intent
SPP	Space Packet Protocol
SRS	Space Research Service
SRT	Sardinia Radio Telescope
S-S/C	Shepherding Spacecraft
SSI	Solar System Internetwork

SSOC	Sagamihara Space Operations Center
STFC	Science and Technology Facilities Council
STGT	Second TDRS Ground Terminal
S/X/L	S-band/X-band/L-band
SWAP	Size, Weight, And Power
TC	Telecommand
TCP	Transmission Control Protocol
TDM	Tracking Data Message
TDM	Time Division Multiplexing
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TLM	Telemetry
TM	Telemetry
TOCC	TDRSS Operations Control Center
TOGS	Transportable Optical Ground Station
TOR	Terms of Reference
TRL	Technology Readiness Level
TT&C	Telemetry, Tracking and Control
TWTA	Traveling Wave tube Amplifier
Tx	Transmit
UDP	User Datagram Protocol
UDSC	Usuda Deep Space Center
UK	United Kingdom
USC	Uchinoura Space Center
VBB	Very Broad Band
VESPUCCI	Cube corner retro-reflector (CCR) array for laser ranging
VHF	Very High Frequency
VLBA	Very Long Baseline Array
VLBI	Very Long Baseline Interferometry
VIS-NIR	Visible-Near Infrared
W	Watt

WG	Working Group
WS1	White Sands 1 Ground Terminal
WSC	White Sands Complex
WSGT	White Sands Ground Terminal